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THE MOTION OF THE GALACTIC SYSTEM AMONG THE NEBULÆ.*

BY

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THE PROBLEM.

The concept of absolute motion was banished from the world of phenomena by the experiments of Michelson and Morley in 1887. For the time being, theory, as well as observation, is restricted to the study of relative motions, of motions with respect to specified frames of reference. These frames take various forms, as, for instance, a bench in the laboratory, the surface of the earth, the system of the planets, or the stars in the neighborhood of the sun.

The most fundamental reference frame now available consists of the extragalactic nebulæ that are thinly scattered through the observable region of the universe. The motion of an observer on the earth with respect to the nebulæ represents an apparently simple problem but investigations have led to strange results and have formulated curious questions without as yet reaching a satisfactory final solution.

Since the motion of the earth with respect to the sun is relatively small and is known with great accuracy, observed motions of stars and of nebulæ, as seen from the earth, can be, and generally are, referred to the sun as origin. Thus the

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problem may be restated as that of the motion of the sun with respect to the nebulæ. This motion is evidently a combination of the sun's motion within the stellar system and the motion of the stellar system through the realm of the nebulæ.

The combined motion has been determined, although the uncertainties are large except in the case of the component of motion perpendicular to the galactic plane. The solutions, as will be seen, suggest a velocity of the order of 300 km./sec. towards a point in the sky at galactic latitude, $\beta = +35° \pm$, and galactic longitude somewhere in the quadrant centered on $\lambda = 55°$.

The motion of the sun within the stellar system is not uniquely determined. However, according to the current theory of galactic rotation (a very plausible, but not a necessary, interpretation of existing data), the sun, together with the other stars, is rotating around the center of the galactic system. Consequently, the sun would be moving in the galactic plane, and in a direction at right angles to the direction of the center of the galactic system ($\lambda = 325°$). The motion is usually described as a velocity of the order of 275 km./sec. in the direction, $\beta = 0°$, $\lambda = 55°$.

If this vector is adopted as the motion of the sun within the stellar system, and is removed from the combined motion of the sun with respect to the nebulæ, the remainder, which represents the motion of the stellar system itself, is a velocity of the general order of 100 to 200 km./sec., in the general direction of the higher north galactic latitudes. The uncertainties of the investigation do not justify a more precise statement of the results.

V.2
193

THE DATA.

Observed motions with respect to the nebulæ consist of radial velocities determined by displacements of lines in the spectra of nebulæ. The observed displacements are combinations of two components, one of which is systematic. The systematic displacements are always to the red, and they increase directly with the distances of the nebulæ. These red shifts behave like velocity shifts ($d\lambda/\lambda$ is constant throughout a given spectrum), and are frequently presented as visible evidence of an expanding universe. The validity of this

interpretation has no direct bearing on the immediate problem, and need not be further discussed. Regardless of their interpretation, red shifts introduce systematic displacements in the spectra of distant nebulæ, measured by the relation

$$\frac{d\lambda}{\lambda} = k \times \text{Distance},$$

or, if the red shifts are expressed on the scale of velocities,[1] velocity = (526 ± km./sec.) × (Distance in units of 10^6 parsecs). These systematic red shifts must be removed before the residual motions of the nebulæ can be investigated.

The residual motions represent combinations of the peculiar, individual motions of the nebulæ and the reflection of the solar motion with respect to the system. When the residual motions of many nebulæ, well distributed over the sky, are analyzed as a group, the peculiar motions, since they are presumably distributed at random in all directions, tend to cancel out, leaving only the reflection of the solar motion to emerge from the totality of the data.

The analysis is a simple, routine procedure but an accurate determination of the observer's motion can be expected only if the observed nebulæ are well distributed and the residual motions are known with precision. Neither requirement can be met in practise. Distances and, consequently, the systematic red shifts are uncertain by more or less constant percentages. Only by restricting the investigation to the nearer, brighter nebulæ, can the actual errors in the calculated red shifts be kept reasonably small in comparison with the residual motions. Such nebulæ, however, are few, and those whose distances can be estimated with confidence are poorly distributed; for the most part, they fall into two groups near

[1] In terms of directly observed quantities, namely, red shifts and apparent luminosities, the following provisional relations have been established.

$$\log d\lambda/\lambda = 0.2\, m_n - 4.71$$
$$= 0.2\, m_s - 6.48,$$

where m_n and m_s are apparent photographic magnitudes of nebulæ and their brightest stars, corrected for local obscuration (latitude effect) and for the dimming effects of the red shifts themselves. The latter corrections are negligible for the relatively small distances considered in the present discussion. In terms of velocities, v, the red shifts represent fractions of the velocity of light, $d\lambda/\lambda = v/c$. *Mt. W. Contr.*, *No.* 549; *Ap. J.*, **84**, 270 (1936).

the two galactic poles. From such a distribution, we may expect to derive a good determination of that component of the observer's motion which is perpendicular to the galactic plane but a poor determination of the components which lie in the plane itself. The analysis, as will be seen, confirms this prediction.

The observational data are listed in Table I which contains the available, measured velocities of nebulæ for which the systematic corrections for red shifts, as derived from brightest stars, are not greater than 1000 km./sec. In addition to resolved nebulæ, a few unresolved nebulæ are included because they are members of groups whose distances are reliably known. For instance, NGC 3031, 3034 and 3077 constitute a triple system whose distance is determined by the one resolved member, 3031 (M 81). The large clusters in Ursa Major and in Virgo are included, each as a unit, although 16 velocities are known in the former, and 42 in the latter. The distance of the Ursa Major group, estimated as 1.6 million parsecs, is still rather uncertain although the cluster is rich in late type, resolved nebulæ. The Virgo Cluster is included although the calculated red shift is greater than the adopted limit, because both the distance and the mean velocity are exceptionally well determined.

The corrections for red shifts in resolved nebulæ are derived from the relation,

$$\log \text{vel.} = 0.2\,(m_s - \Delta\beta) - 1.00,$$

where m_s is the photographic magnitude of the brightest star, and $\Delta\beta$ is the "latitude correction" for local obscuration.[2] These corrections are slightly revised in order to take into account the probable dependence of the absolute luminosity of the brightest stars on the stellar contents of the nebulæ. For unresolved nebulæ a similar relation is available, in which the magnitude of the brightest star is replaced by the magnitude of the nebula itself,

$$\log \text{vel.} = 0.2\,(m_n - \Delta\beta) + 0.77.$$

[2] *Mt. W. Contr.*, No. 549; *Ap. J.*, **84**, 270 (1936). The formula expresses the empirical relation between apparent magnitudes of brightest stars and red shifts expressed as velocities. The latter quantities are derived from the observed velocities less the galactic rotation—a sufficiently close approximation for our purpose.

TABLE I.

Velocities of Nearby Nebulæ.

	Type	m_n.	m_s.	Dist.	v(obs.).	v(corr.).
Virgo	42 Velocities			2.3	+1180	− 60
Ursa Maj.	16 Velocities			1.6	770	− 70
4725	Sb	10.7	19.8	1.34	1100	+310
4826	Sb	9.4	18.5	0.73	150	−230
5005	Sc	11.3	19.7	1.76	900	− 30
5055	Sb	10.4	19.2	0.97	450	− 70
5194, 5195	Sc	9.0	17.6	0.66	250	−100
3351, 3368, 3377, 3379, 3384, 3412, 3489	Group of 12 Neb.			1.6	785	− 45
3521	Sbc	10.1	19.9	1.77	730	−200
3623	Sa	10.4		1.07	725	+165
3627	Sc	9.8	18.7			
2683	Sc	10.6		1.5	400	−380
2841	Sb	10.1		1.15	600	− 20
2903	Sc	10.1	18.9	1.25	350	−310
3310	Sb	10.7	19.9	1.40	960	+310
3031	Sb	7.9	18.4	0.90	45	−425
3034	Ir	9.0				
3077*	Ir	11.2				
4236*	Sc	11.1	18.9	1.12	40	−560
5457	Sc	8.8	18.0	0.85	300	−150
5866	So	11.2		1.7	650	−340
5907	Sb	11.6			400	−490
5248*	Sc	11.1	19.2	1.34	1010	+290
5363	Ir	11.1		1.66	1050	+180
5364	Sc	11.6	19.7			
5236	Sc	7.7	18.3	1.13	475	−115
5253	Ir	10.8				
2775	Sa	11.2		1.95	1100	+ 80
3115	E	9.5		0.90	600	+120
2537*	Sc	11.9	18.8	1.09	300	−270
2366*	Ir	12.2	18.7	1.04	130	−420
2403	Sc	9.9	17.8	0.70	130	−240
7217	Sb	10.9		1.70	1050	+160

TABLE I—*Continued.*

		m_n.	m_s.	Dist.	v(obs.).	v(corr.).
7331	Sb	10.7	19.1	0.87	500	+ 40
278	Sbc	10.8	19.8	1.6	700	−140
1003	Sc	12.5	19.9	1.51	480	−430
428*	Sc	12.2	19.7	1.6	1100	+260
628	Sc	11.0	18.8	1.09	600	+ 30
864*	Sc	12.1	19.9	1.80	1370	+420
908*	Sc	10.0	19.5	1.77	1750	+820
936	SBa	11.3		1.90	+1410	+415
1052*	E	11.5				
1068	Sb	9.9	18.6			
1084	Sc	11.1	19.9			
1087	Sc	11.0				
247	Sc	10.6	19.0	1.08	− 30	−600
253	Sc	8.1	18.0			
613*	Sc	11.0	18.5	1.61	+1680	+830

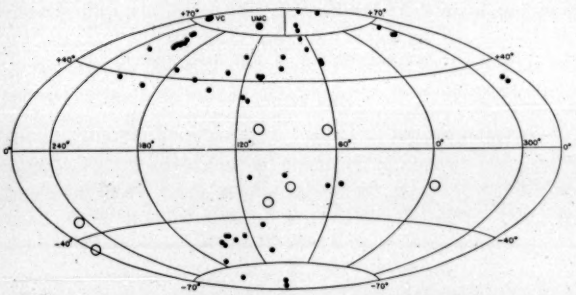
m_n and m_s are apparent photographic magnitudes of nebulæ and their brigtest stars, corrected for the latitude effect (local obscuration). Distances, expressed in units of 10^6 parsecs, are derived from m_n and m_s by methods described in *Mt. W. Contr.*, No. 548; *Ap. J.*, **84**, 158 (1936). The group, 3351–3489, appears to include at least a dozen nebulæ, and the distance is estimated from the mean m_n of the group.

Asterisks indicate nebulæ for which velocities, hitherto unpublished, were very generously contributed by Dr. Mayall of the Lick Observatory. Unpublished velocities of 5363, 5364, and of several nebulæ in the Virgo Cluster and in the Ursa Major group were kindly furnished by Milton Humason of the Mount Wilson Observatory. The remaining velocities (except that for 1003 which was published by Humason, *A. S. P.*, **50**, 55 (1938)) were taken from *Mt. W. Contr.*, No. 549; *Ap. J.*, **84**, 270 (1936).

Because the distribution of the nebulæ in Table I is unsatisfactory for the particular problem, the analysis of the data has been carried out in two ways. In one solution, each of the nebulæ (except those in the Ursa Major and the Virgo Clusters) was included with unit weight. In the second solution, the sky was divided into areas, and the mean velocity for each area was given equal weight, regardless of the number of nebulæ in the area. The areas are shown in Fig. 1, in which the distribution of the nebulæ is presented. The adopted pattern was arbitrarily selected. It consists of the polar caps and, in each hemisphere, two zones of latitude, one covering 70° to 40°, the other, 40° to 10°, divided into strips covering

60° in longitude. The northern polar cap has been divided into two parts in order to separate the two clusters from the field nebulæ. The nebulæ in Table I are very unequally distributed in 16 out of the total of 27 zones in the sky.

FIG. 1.



Distribution of the nebulæ in Tables I and II. The field nebulæ listed in Table I are represented by small black discs; the members of the Local Group listed in Table II, by large open circles. Positions are plotted in galactic coördinates on the Aitoff equal area projection of the sky.

THE METHOD OF ANALYSIS.

The form of the solution follows the usual procedure. For convenience, galactic coördinates are used throughout. The reflection of the sun's motion is represented by an unknown velocity, V, directed towards an unknown anti-apex (λ_0, β_0). This vector is projected on three rectangular coördinates whose origin is at the sun. The components X and Y lie in the galactic plane (X positive in the direction of $\lambda = 0°$), and the component Z is perpendicular to the plane (positive to the north). The reflection of the sun's motion on a nebula observed in the direction λ, β, is merely the sum of the projections of the three components on the line of sight to the nebula. Thus, each nebula furnishes an equation of the form

$$X \cos\lambda \cos\beta + Y \sin\lambda \cos\beta + Z \sin\beta = v,$$

where v is the observed velocity which is the sum of the peculiar, individual motion of the nebula and the reflection

of the sun's motion. If the peculiar motions are distributed at random, and, consequently, tend to cancel one another, the unknown components of the sun's motion, X, Y, and Z, are readily determined by a least squares solution of a suitable number of equations. From the three components, the total velocity, $V = \sqrt{X^2 + Y^2 + Z^2}$, and the direction of the anti-apex, $\tan \lambda_0 = Y/X$, $\tan \beta_0 = Z/\sqrt{X^2 + Y^2}$, are immediately determined. The sun's motion is the velocity, V, in the direction of the apex (opposite to the anti-apex).

THE RESULTS.

When the nebulæ in Table I were used individually, giving unit weight to each object, the components of the solar motion were found to be

$$X = -161 \pm 80 \text{ km./sec.}$$
$$Y = -212 \pm 60$$
$$Z = -167 \pm 35.$$

These results indicate a solar motion of 314 km./sec. in the directions, $\lambda = 53°$, $\beta = +32°$.

When the nebulæ were grouped in the 16 areas previously described, and equal weights are assigned to each area, the components were found to be

$$X = -65 \pm 90 \text{ km./sec.}$$
$$Y = -210 \pm 61$$
$$Z = -181 \pm 42.$$

These results indicate a solar motion of 285 km./sec., in the direction $\lambda = 73°$, $\beta = +39°$.

It seems likely that the two methods of analysis represent extreme assumptions concerning the weights of the various data, and that the most probable values for the solar motion lie between those listed above. For this reason, together with the large uncertainties in the components of motion, it seems advisable to adopt the mean of the two determinations as a provisional estimate of the order of the solar motion, and to attempt no further refinement until more extensive and accurate data become available. Thus we conclude that the data in Table I suggest that the sun is moving with a velocity

of the order of 300 km./sec. in the general direction $\lambda = 63°$, $\beta = +35°$. This apex lies in the constellation of Draco.

Various other solutions have been made, in attempts to reduce the effects of distribution, but they add little information. The large, negative value of Z persists, indicating a large, positive latitude of the apex but the longitude of the apex ranges over an entire quadrant. One set of solutions may be mentioned in greater detail. By including fainter, more distant nebulæ, it is possible to improve the distribution at the cost of increasing the uncertainties in the corrections for red shifts. A limit of 2000 km./sec. was adopted for the corrections, and, in this way, the number of nebulæ was increased to 112, distributed in 21 of the 27 areas. The corrections for red shifts were derived in various ways—from brightest stars, from total magnitudes in groups, and even from total magnitudes of individual nebulæ. The most probable results appeared to be

$$X = -227 \pm 67 \qquad V = 300$$
$$Y = -88 \pm 62 \qquad \lambda = 21°$$
$$Z = -175 \pm 32 \qquad \beta = +35°,$$

which agrees fairly well with those derived from Table I, except for the large discrepancy in the longitude of the apex.

The final step in the investigation consists in removing from the solar motion with respect to the nebulæ, that part which represents the sun's motion within the galactic system. The latter motion is essentially the galactic rotation—the motion of the sun in its orbit around the center of the system—and the current value, as previously mentioned, is 275 km./sec. in the direction, $\lambda = 55°$, $\beta = 0°$. When this motion is removed from the sun's motion with respect to the nebulæ (300 km./sec. towards $\lambda = 63°$, $\beta = +35°$), the remainder must represent the motion of the galactic system among the nebulæ. This last motion is evidently small—of the order of 150 kilometers (or 100 miles) per second, in the general direction of the north galactic pole. A relatively small velocity, and a high inclination to the plane of the Milky Way, seem to be definitely indicated although precise numerical values cannot be derived from the data now available.

An inspection of the data used in the investigation, and a study of the possible ways of assembling additional data, suggest that the situation will not be much improved until distances of nebulæ have been determined with an accuracy much greater than that of the estimates now available. The project calls for an extensive program of precise photometry, both of the nebulæ and of stars involved, and a thorough study of small scale distribution, including the luminosity function for small groups of nebulæ.

MOTIONS WITHIN THE LOCAL GROUP.

Table I does not include the nearest of the nebulæ. The galactic system appears to be one of a dozen nebulæ which form a "local group," more or less isolated in the general field. The members of the local group are our nearest neighbors in space, and they were the first extragalactic systems to be recognized and studied in detail. For some time it has been realized that the law of red shifts may not operate within the local group. Since, presumably, the members are physically connected, definite information concerning the presence or absence of a systematic recession should have an important bearing on the interpretation of red shifts. For this reason, the nebulæ in the local group were not included in the general solutions but were examined separately.

The observational data are listed in Table II, the only new datum being a revised velocity of M 33.[3] The Magellanic Clouds, as satellites of the galactic system, are perhaps in a special category, and the status of the two systems, NGC 6946 and IC 342, is somewhat uncertain because of heavy, local obscuration in the low latitude, $\beta = +11°$, in which they are seen. With these reservations, the data can be assembled into four groups, each representing a fairly limited area of the sky, and used for determinations of the solar motion.

Unlike the field nebulæ, the groups are well distributed in longitude but not in latitude. For this reason, the X and Y components (in the galactic plane) are more reliably deter-

[3] The tabulated velocity represents a mean of the Mt. Wilson results (+ 320 km./sec.) and unpublished measures from the Lick Observatory (+ 180 km./sec.), which Dr. Mayall has very kindly permitted the writer to use in the present discussion.

V.2
193

mined than the Z component, and, since the last quantity is relatively small, the total velocity, V, is also fairly well determined. The observed velocities, uncorrected for red shifts, lead to a solar motion of 265 km./sec. in the direction, $\lambda = 52°$, $\beta = -12°$, the latitude being the most uncertain. This motion is almost identical with the assumed galactic rotation.

When the observed velocities are corrected for red shifts, the direction of the solar motion is not materially altered ($\lambda = 58°$, $\beta = -19°$) but the velocity is almost doubled, $V = 475$ km./sec. The explanation appears to be as follows: with the exception of the Magellanic Clouds, which, as close

TABLE II.
The Local Group.

Neb.	Dist.[1]	V(obs.).	λ.	β.
LMC	0.85	+276	247°	−33°
SMC	0.95	+168	269	−45
M 31[2]	6.8	−250	89	−21
M 33	7.2	−250	103	−31
NGC 6822	5.3	−150	354	−20
NGC 6946	16.0	−150	64	+11
IC 342	22.0	− 25	106	+12

[1] Distance in units of 10^8 light years.

[2] The data for M 31 includes those derived from the two satellites, M 32 and NGC 205.

satellites of the galactic system, are relatively unaffected by red shifts, the members of the local group are seen in the general direction of the apex of the solar motion as determined from the uncorrected velocities. The determination from uncorrected velocities indicates that, as far as the radial velocities are concerned, the galactic system is at rest with respect to the other members. Consequently, when corrections for red shifts are applied, the residual velocities are systematically negative (the galactic system, and the other members as a unit, are approaching one another).

The assumption that the galactic system, situated at one end of the local group, is approaching the other members (or

the center of the group), seems reasonable but is inconsistent with the results derived in the first section of the present investigation. With respect to nebulæ in the general field, the galactic system is moving at right angles to the direction of the other members of the local group. Consequently, with respect to the fundamental reference frame, the other members of the local group, as a unit, are moving towards the galactic system.

This situation seems to indicate *either* that the galactic system, with its satellites, is a triple nebula in the general field but in the immediate vicinity of a small group of nebulæ which is moving towards the galactic system, *or* that the law of red shifts does not operate within a physically connected system such as the local group.

The latter alternative seems the more likely, and consequently, the investigation may contribute to the interpretation of red shifts. The results are consistent with the current theory of an expanding universe because the theory presents a sort of cosmic repulsion which, within a physical group of nebulæ, may be overcome by the gravitational field of the group.

Nevertheless, the results do not establish the expansion as the only possible interpretation of red shifts. Other data are available which, at the moment, seem to point in another direction. Much further information must be assembled before we may hope to formulate a consistent conception of the universe, derived from the observed characteristics of the sample available for inspection.

STELLAR ENERGY.*

BY

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This lecture should begin by an apology to the audience. The speaker tonight should be the man whose recent—and brilliant—work has inaugurated a new and very promising stage of astrophysical study—Professor H. A. Bethe of Cornell. The planners of the program can plead but one excuse—his results had not been announced when it was prepared.

They are not yet published in detail; but Professor Bethe has most generously given me a full copy of the proof of his forthcoming paper,[1] and amplified this in personal conversation. What there is of novelty in the present discussion should be credited entirely to him and not to myself. Indeed my report, apart from this, is mainly upon the work of others in a field in which I did a little pioneering a good many years ago.

A century of precise measurement has furnished astronomers with a large accumulated capital of facts about the stars. One of the most remarkable things that is thus revealed is that the stars differ greatly among themselves in some properties, and relatively little in others. For example, the luminosity—the rate of radiation of energy—ranges (roughly) from a million times the Sun's luminosity to a thousandth part of it, a ratio of a billion to one. The diameters run from at least 1000 times the Sun's down to 1/30 or less, a range of thirty-thousand-fold. For the masses, the range is roughly from 100 times the Sun to 1/10 of the Sun, a thousand-fold. But surface temperatures more than ten times the Sun's or less than 1/4 that of the Sun are practically unheard-of, so that the known range is only forty-fold.

* Presented at a symposium on the progress of astrophysics held jointly with the American Philosophical Society on Friday, February, 17, 1939.

[1] *Phys. Rev.* **55**, 434, 1939.

Why should such enormous diversities exist? The limitation of our study is set, on one side, by the obvious fact that we cannot see a star unless it shines—that is, unless it gives out enough light to be perceptible at stellar distances. This obviously sets a limit to our knowledge of *faint* stars, and of *small* stars—which, other things being equal, will shine less brightly because they have fewer square miles of surface, and still more to the study of *cool* stars (of low surface temperature). The heat radiation per square mile varies as the fourth power of the temperature, and a forty-fold increase in the latter changes the former by a factor of about two and a half million. Moreover, at low temperatures, most of the radiated energy is in long infra-red waves, invisible to the eye, so that a star—like a mass of hot iron—ceases to be visible in the dark, long before it stops giving out heat.

But there is no such limitation on the side of great brightness. If we fail to find still brighter stars—though we are fishing for these in very wide waters—it must be because there are no such fish in our sea. Nature herself must in some way set a limit to the brightness attainable by a star—at least as a permanent affair, for we know that the short-lived outbursts of supernovæ are enormously more intense. Such a limitation would explain why stars of very large diameter are never found to be very hot—if they were, they would give out too much light,—but it has no obvious relation to the mass of a star.

A notable advance was made more than twenty years ago when it was found observationally (first by Halm) that there is a close relation between the mass of a star and its luminosity. All later work has confirmed this, and it now appears that, over almost if not quite the whole available range, the total heat-radiation of a star is nearly proportional to the fourth power of its mass. The most remarkable feature is that, for a given mass, the luminosity does not depend much upon the size of the star—the large ones are cool, and give out less heat per square mile, the small ones hot, and give out more; but the net product is nearly the same.

Eddington's explanation of this, completed fifteen years

V.2
193

ago, marks the first, and, even now, the greatest success of modern atomic physics in interpreting the stars.

Since the work of Lane in 1870, it has been realized that, if the familiar laws of perfect gases could be applied to the interior of the Sun, the central temperature must be many millions of degrees. The result may be written

$$T = 11.5 \frac{MY}{RX} \mu,$$

where T is the temperature in millions of degrees, M the star's mass and R its radius, μ the mean molecular weight of the material, and Y and X quantities depending on the "density-model," that is, the law in accordance with which the density increases toward the center.

Calculations for different laws of density-distribution show that the "model" has a rather small influence. If the density were everywhere the same, X and Y would be 1 at the star's center. On the model to which Eddington's calculations led, the central density was 54 times the average ($X = 54$); but $Y = 92$, so that the central temperature for the Sun comes out 19,700,000°. A model recently calculated by Chandrasekhar makes $X = 88$, $Y = 171$, and the temperature 22,300,000°; still another, reported by Bethe, 20,300,000°—all provided that $\mu = 1$. There are good reasons to believe that these "models" give a fairly correct idea of the situation, and therefore that the central temperature of the Sun is close to twenty million degrees—provided that the molecular weight is 1.

But, under ordinary circumstances, μ is 1 for hydrogen, 4 for helium, 16 for oxygen, 56 for iron, and so on, so that the calculated internal temperature of the Sun would depend enormously on its assumed chemical composition.

Fortunately for us theorists, the situation is simpler inside the stars, for the outsides of the atoms—the electrons which surround the nucleus—are pretty well knocked off. A hydrogen atom (with one electron) is broken into two particles, a helium atom into 3, one of oxygen into 9, and one of iron into 27 (or perhaps 25, if the two tightest bound electrons stay with the nucleus).

The average weight of a free particle (which is what counts) then comes out 1/2 for hydrogen, 4/3 for helium and nearly 2 for all heavier atoms. So we can conclude that the central temperature of the Sun is close to 10 million degrees if it is pure hydrogen, 27 million if it is all helium, and 40 million if it is all composed of heavy atoms—and the result for any assumed mixture can easily be computed.

The temperature of the Sun's surface is but a few thousand degrees. Heat will flow outward from the hot interior "down grade" and the surface will adjust its temperature so that it loses by radiation into space just the amount which it gains by transmission from the deep interior. The rate of this transmission thus determines how bright and hot the Sun (or any other star) will be; it takes place mainly by the transfer of radiation from atom to atom through the gas; and the net opacity, which determines the rate of transfer, may be calculated with considerable accuracy, on principles developed by Kramers.

When the net flow of heat out to a star's surface is thus calculated, it is found that it depends relatively little on the "model," and not much upon the radius, but changes rapidly with the mass—at very nearly the rate indicated by observation.[1]

The mass-luminosity relation is thus explained—and with it the fact that stars of mass less than one-tenth the Sun's have not so far been detected—they are presumably too faint to be seen; and our failure to discover very large masses is connected with the absence of stars of very great luminosity.

Eddington's theory, however, predicts that the luminosity of a star, other things being equal, should change very rapidly with the mean molecular weight of its material (about as its seventh power). A star composed almost entirely of heavy atoms (with $\mu = 2$) will be so hot inside that it will shine brightly, whereas one composed mostly of hydrogen will be cooler inside, and fainter outside by several hundred-fold (the exact amount involving refinements of calculation omitted here).

[1] Certain complications which arise in the more massive stars where radiation-pressure becomes a sensible fraction of gas-pressure, are neglected in the above account, for brevity.

The observed luminosity of the Sun is about midway between these limits, and may be accounted for, according to Strömgren's calculations, if one-third of the material, by weight, is hydrogen, and the rest heavy atoms; or with more hydrogen if helium is present; for example, 60 per cent hydrogen, 36 per cent helium, and 4 per cent heavy atoms. The mean molecular weight comes out 0.98 and 0.67 in the two cases, and the central temperature 19 million and 13 million degrees.

Repeating his calculations for other stars for which we have reliable data, Strömgren finds very nearly the same composition for Sirius A—the bright star, not its faint companion—for Capella, and for several others. Some stars contain less hydrogen, e.g. ζ Herculis A, which is four times as bright as the Sun though of very nearly the same temperature and mass. Its computed hydrogen content is 12 per cent (if there is no helium).

The observed mass-luminosity relation is now completely accounted for on principles derived from general atomic theory—but a new phenomenon takes its place to be explained. Why should so many of the stars contain almost the same amount of hydrogen? This is obviously not the kind of question which can be answered by a general theory of the type already described; and there are other much more obvious properties of the stars of which this is also true. For example, if we plot the luminosities (or the stellar magnitudes) of the stars against the surface temperatures (or the special types) we obtain a now very familiar diagram which shows marked peculiarities. The greater portion of the dots representing the stars lie in a narrow strip—indicating the existence of a "main sequence," having at one end bright, white stars, of great luminosity, large mass, and high surface temperature; and at the other faint red stars, their opposites in all three respects. The Sun is a typical member of this sequence, about midway in it. Calculating the diameters, we find that the stars at the top of the sequence are larger and less dense than the Sun, those at the bottom smaller and denser; but these differences are not very great, and most of the enormous range in brightness from one end to the other arises from the differences in surface temperature. The

central temperature varies still less—it is some 30 or 35 million degrees for the stars at the top of the list, and may be as low as 12 or 15 million for the faint red ones at the bottom.

Almost as conspicuous as the main sequence (and indeed more so in a list of naked eye stars, which automatically picks the bright ones) is a wider, but definite band, beginning with stars of about the Sun's surface temperature (Class G) but some fifty times the Sun's brightness, and extending to some of the reddest known stars, which give off several thousand times as much heat (though not visible light) as the Sun.

These giant stars (so named for their brightness) deserve the name for their size. Capella, which is a little cooler than the Sun, and 120 times as luminous, must have about 16 times the Sun's diameter. At the other end of the giant sequence come huge objects several hundred times as big as the Sun. The masses—according to the rather scanty evidence which alone is available, after careful searching—are about the same as for main-sequence stars of equal luminosity. For Capella alone is an accurate value known, 4.2 times the Sun's mass. This makes its density hardly more than 1/1000 that of the Sun, and its central temperature (if built on a similar model) less than 6 million degrees. For the great red star ζ Aurigæ, the mean density is one nine-millionth part of the Sun's, and the central temperature (for the same model) but 1,200,000 degrees.

At the top of the diagram are scattered points representing the super-giant stars, extremely luminous, and with all sorts of surface temperatures. They must be of large diameter, and low density and internal temperature. The region below the giants and to the right of the main sequence is almost vacant, as is also that below the main sequence to the left. It is in this last region that we should find points representing stars with internal temperatures higher than twenty or thirty million degrees—and there are hardly any,[2] except down at the bottom, the famous white dwarfs—like the companion of Sirius—somewhat less massive than the Sun, less than one per cent as bright, and comparable in

[2] There are a few white stars about as bright as the Sun for which we have not yet sufficient data to say anything definite.

diameter with Uranus or Neptune. The mean densities of these bodies are as great as 100,000 times that of water, and they represent a "degenerate" state of matter, in which as many electrons are jammed into every cubic centimeter as the quantum-laws will permit. They are surprisingly well understood, but do not belong to our present problem.

The luminosity-spectrum diagram reveals one more important fact. There are a great many stars with central temperatures of 20 to 30 million degrees, a good many with lower central temperatures, and very few, if any, which are hotter inside, except the white dwarfs. Why should this be? This ties up with an older and more fundamental question. Why do the stars keep on shining?

When first the Sun's heat was measured, it was realized at once that it could hardly be maintained, even for the duration of history, by ordinary chemical combinations—what we now describe as reactions between whole atoms. A far larger source of energy is found in a slow contraction, compressing the gas and turning the gravitational potential energy into heat, and this explanation—due to Helmholtz and Kelvin,—was still accepted forty years ago. The energy supply thus available for the Sun's past history is about thirty million times its present annual expenditure (depending somewhat on the assumed model). But at least half this must still be stored inside the Sun in the form of heat, so that less than fifteen million years of sunshine can be accounted for.

But the Sun has been shining and warming the Earth, very much as now, throughout geological history, which is certainly a hundred times as long as this. There is only one place in the known universe to look for so vast a store of energy—and that is in the minute nuclei of atoms. From these nuclei is liberated the energy of radio-activity—which is of the required order of magnitude, though rather small. But radio-activity itself will not meet our needs, for it takes place at a rate uninfluenced by conditions external to the nucleus—such as the surrounding temperature. To account for the observed variation of luminosity with mass, we would have to assume that in some inscrutable way the amount of active material had been exactly proportional "in the beginning" to the mass of each star, so as to provide the proper

heat supply to maintain its radiation; and also that practically none of it had been allowed to enter the Earth or the other planets—for otherwise their surfaces would be red-hot or even white-hot.

It is necessary, therefore, to assume that the great store of energy upon which the stars draw becomes available only under stellar conditions—that is, obviously, at temperatures of millions of degrees.

The whole course of nature teaches that it would not become available abruptly, but at a rate increasing with the temperature, and probably increasing very rapidly. But here appears a difficulty. If too much heat should at any time be liberated inside a star for the steady process of escape to the surface to carry off, would not the material grow hotter, "turn on" a still more rapid supply of heat, till some tremendous explosion ensued?

The answer lies in a curious property of a gravitating star. As we have already seen, it must grow hotter inside if it contracts; but the gravitational energy released by the contraction is more than enough to supply this heat, and leaves a balance available for radiation. Only as heat is lost into space can the temperature of the interior rise. If just enough heat is liberated from some sub-atomic process, there will be a steady state; if too little, contraction will supply the rest; if too much, this contraction will be converted into an expansion. This expansion will lower the internal temperature, and shut off the over-supply. The Sun has an internal store of heat equal to at least eight million years' outgo. The sudden introduction into the interior of even a thousand years' heat supply would therefore produce very little effect (unless it were localized in a small region, when it might cause trouble).

One other thing was clearly understood, twenty years or so ago; the reactions which provide the stars with their energy must be accompanied by a perceptible loss of mass. The theory of general relativity indicated that mass and energy should be interconvertible, at the rate of c^2 units of energy (ergs) for one unit of mass (gram), where c is the velocity of light. The Sun's rate of loss of energy by radiation (3.8×10^{33} ergs per second) is far too great to be comprehensible in

ordinary terms; but, if measured in mass-units, it means that the Sun is actually losing 4,200,000 *tons* of energy every second! The Sun's mass (2×10^{33} g.) is so great that even at this enormous rate, it would take 15 billion years to reduce it by one part in a thousand.

The nature of the process—or, at least, of one process—by which this transformation of mass into energy can take place, is now well understood, since it can be made to happen in the laboratory, in many different ways. This is the transformation of atoms of one sort into another, with the appearance of an amount of energy corresponding to the change in total mass; and it is to this that we now look as the source of stellar energy.

The alternative hypothesis, that positively and negatively charged particles may utterly annihilate one another, with the appearance of the whole amount of energy corresponding to the sum of their masses, has now been dropped since no evidence of it has been observed. It does appear to happen for positive and negative electrons; and judgment may well be reserved about "heavy electrons" (mesotrons) till more is known about them.

The masses of the lighter atoms (including their outer electrons) are given in Table I. They can be very accurately

TABLE I.
*Masses of Light Atoms.**

Name	Symbol	Charge	Mass
Electron	e	−1	0.00055
Neutron	n	0	1.00893
Hydrogen	H	1	1.00813
Deuterium	H^2	1	2.01473
Helium	He^3	2	3.01699
Helium	He^4	2	4.00386
Lithium	Li^6	3	6.01686
Lithium	Li^7	3	7.01818
Beryllium	Be^9	4	9.01504
Boron	B^{10}	5	10.01631
Boron	B^{11}	5	11.01292
Carbon	C^{12}	6	12.00398
Carbon	C^{13}	6	13.00761
Nitrogen	N^{14}	7	14.00750
Nitrogen	N^{15}	7	15.00489
Oxygen	O^{16}	8	16.00000

* These values are from Bethe's computations, with some changes from his latest work.

determined,—mainly with the mass-spectrograph. The various isotopes—atoms of different weight, but the same chemical properties—are of course listed individually.

From the table it appears that if four hydrogen atoms could in any way be converted into one helium atom, a loss of mass of 0.02866 units would result. This is 1/141 of the original mass. If, therefore, a thousandth part of the Sun's mass were hydrogen, and could be transmuted into helium, energy enough would be released to keep the Sun shining for 106 million years.

The excess of the tabulated mass above an even value evidently represents the possible value of the given atom as a source of energy. This excess is fairly considerable for most of the lighter atoms; but oxygen, carbon and helium are relatively very stable. Some atoms heavier than oxygen are still further "down"; but the differences are small and need not concern us here. Per unit of mass, hydrogen is much the best source of energy.

Two types of nuclear reaction, in the laboratory, give rise to reactions of the sort considered, the penetration into a heavier nucleus of a neutron, or of a charged particle (proton, deuteron, or alpha-particle). The former are the easiest to produce artificially—since the other nucleus does not repel the neutron. They occur in great variety, and liberate large amounts of energy. For this very reason, it appears that they are not of much astrophysical importance. They happen *too* easily. If there were a lot of neutrons in the interior of a star, they would all collide with atomic nuclei of one sort or another—sometimes building up a heavier atom, sometimes causing the emission of some other particle—and they would be used up in the process, in the twinkling of an eye. There might be an almost explosive outburst of heat (under the altogether unnatural conditions which we have imagined) but anyhow the neutrons would be gone, and similar reactions would occur in future only if "new" neutrons were produced by other nuclear reactions. A careful study by several investigators has shown that this should happen so very rarely that its effects can be neglected.

We are left, then, as a steady source of energy, with the penetration of one charged nucleus into another. The

repulsion between the two is always so great that only an exceptionally violent head-on collision between particles moving much faster than the average would be effective. The probability of such a collision has been calculated. It diminishes very rapidly with the charges of the particles, so that a proton is vastly more likely to succeed than an alpha-particle, while even it stands very little chance of getting into a nucleus with a larger charge than oxygen (provided, at least, that the temperature is not more than twenty million degrees).

What happens after the proton gets in depends on the individual peculiarities of the nucleus which it hit. It may simply go in and stay—producing a new nucleus greater by 1 in both charge and mass; or a positive electron may be ejected, leaving a nucleus of the same charge as before but greater mass; or the old nucleus may break up into two or more pieces—one of which is usually an alpha-particle. None of these changes can happen if the hypothetically resulting nucleus is heavier than the reacting particles, for a quite impossible amount of energy would have to be supplied, from no known source. If the mass of the product is less than that of the two particles, the excess energy will appear as kinetic energy when the nucleus breaks up, or an electron is ejected;[3] in the first case, it appears as radiation—a gamma-ray.

All three processes occur in the stars.

The astrophysical importance of reactions of this type were first pointed out by Atkinson. They have been discussed by von Weizsäcker, Gamow and Bethe, and enough is now known about the properties of nuclei to give a pretty clear picture of what would happen.

First. The one stable thing in this microcosm of change is the alpha-particle (He^4). Apparently nothing can happen to it. The nuclei which might imaginably be formed by collision with a proton (He^5 or Li^5) are unstable, and do not exist at all; a collision of two alpha-particles would give Be^8, which is slightly unstable, and breaks up again. Three fast-moving alpha-particles, colliding simultaneously,

[3] Much of the energy in this case is believed to be carried off by that elusive particle, a neutrino.

might possibly form C^{12} with liberation of energy; but such an event is so very improbable that it can be neglected, except at much higher temperatures.

If, then, hydrogen is "the fuel of the stars" helium is the ashes.

Second. The other light nuclei, up to and including boron, are highly susceptible to proton collisions. The different ones go through various transformations, but every sequence ends irrevocably in helium—for example, $Li^7 + H = 2He^4$, $B^{11} + H = 3He^4$. (In this last case the nucleus breaks into three pieces—all helium.) Hence these elements, if originally present in a star, would be successively exhausted as the reactions went on. If we imagine a mass equal to the Sun's slowly contracting from a large size, with increasing central temperature, then, according to Bethe, the reaction which eats up deuterium would happen fast enough to supply the star's radiation, when the central temperature was 360,000° (more or less, depending on the amount present).

So long as any considerable amount of deuterium remained, the star would not contract further. As it was exhausted a new contraction would begin, to be halted when the central temperature was about 2,000,000° and lithium began to be transformed and used up. Beryllium would have a similar fate at a central temperature of 3½ million degrees, and the two isotopes of boron at five and nine million. Since the Sun's central temperature is much higher than this, there can be practically none of any of those elements left in its interior. At the surface, spectroscopic evidence shows that all three are present, but in very small quantities.

Third. At a temperature somewhat above fifteen million degrees, carbon begins to be attacked, and something quite new happens, which is tabulated by Bethe as follows:

$C^{12} + H = N^{13} + \gamma$	2,000,000 years
$N^{13} = C^{13} + \epsilon^+$	10 minutes
$C^{13} + H = N^{14} + \gamma$	50,000 years
$N^{14} + H = O^{15} + \gamma$	50,000,000 years
$O^{15} = N^{15} + \epsilon^+$	3 minutes
$N^{15} + H = C^{12} + He^4$	2,000 years.

The proton goes into C^{12} and builds up N^{13} (the spare energy

escaping as a γ-ray). This is one of the artificial radio-active elements, which has been produced in the laboratory. It emits a positive electron (ϵ^+) and goes over into the carbon isotope C^{13}. The next proton turns this into ordinary nitrogen N^{14}, and another produces a radio-active oxygen O^{15} which goes over into "heavy" nitrogen N^{15}. A proton collision might build this up into ordinary oxygen O^{16}; but Bethe calculates that it is ten thousand times more probable that it would split the nucleus into two parts, one of which is helium, and the other the original carbon C^{12}, ready to be used over again! The carbon is not consumed, but acts as a catalyst for the transformation of hydrogen into helium, and we have a regenerative process, which should continue until all the hydrogen has been transformed.

Four of the six steps here described have already been observed in the laboratory. The other two (involving collisions of protons with nitrogen) can reasonably be inferred from known data. The average length of time during which an atom of each kind may be expected to last before its next adventure, is given in the table. The $N^{14} + H$ reaction is the slowest; it will then be the "bottle-neck" for the whole process. Bethe's calculations show that it would supply energy enough for the Sun at a temperature of 18,300,000° (assuming 35 per cent of hydrogen and 10 per cent of nitrogen). As the rate of reaction increases as the 18th power of the temperature, it would do the work, with 1 per cent of nitrogen, at a temperature of 20,800,000°. Now these temperatures, which are calculated from pure nuclear theory, agree excellently with the central temperature of the Sun, as calculated from astrophysical data. An almost equally good agreement is found for Sirius, (22 million from theory, 26 from observation) and for the very hot and massive star Y Cygni, (30 and 32 million). Moreover, the gradual changes in light, diameter, density and surface temperature for stars of different mass along the whole main sequence are in excellent agreement with the results of the theory.

It appears, then, that one great part of the problem of the source of stellar energy has been fully solved. The main sequence is explained in detail.

There are still worlds left to conquer. The very rapid

energy-liberation in the giants cannot be accounted for in the same way. It might be assumed that they are built on the same sort of model as the main-sequence stars, but contain larger quantities of lithium, beryllium or boron—but this is a far-fetched idea and does not explain why they form a sequence in which the reddest stars are the brightest. It is also possible, as Gamow, Öpik, and others have suggested, that they are built on quite a different model with relatively small and dense cores, which may be as hot as those of the main-sequence stars or hotter. Much more is likely to be done on this problem within a few years.

Reactions involving heavier nuclei are possible, but they would occur at significant rates only at higher temperatures, and so would not have a chance to happen if there were any carbon in the stars—as there assuredly is. If, at the other extreme, we had a star composed originally of pure hydrogen, it might get energy by the following chain of reactions, also according to Bethe:

$$\begin{aligned} H + H &= H^2 + \epsilon^+ \\ H^2 + H &= He^3 \\ He^3 + He^4 &= Be^7 \\ Be^7 + \epsilon^- &= Li^7 \\ Li^7 + H &= 2He^4. \end{aligned}$$

Two protons form a deuteron—a slow reaction, the latter goes over almost at once into He^3; this with an alpha-particle forms a known isotope of beryllium, which turns to lithium and then to helium—the net result being, as usual, the building of four hydrogen atoms into one of helium.

The rate of this process changes much more slowly with the temperature than that of the carbon cycle, Bethe suggests that it may supply the energy in the coolest stars of the main sequence. Present data do not suffice for a decision.

Two large questions remain to be mentioned.

First. What will be the history of a star? The first portion, till the carbon-cycle is "turned on" has already been described. The star will then keep shining as a member of the main sequence, for a very long time—gradually using up its hydrogen, increasing the mean molecular weight, and growing brighter, hotter, and a little larger. At last, when the hydrogen is exhausted, it must contract, become fainter as well

as smaller, and end up, if of small mass, as a white dwarf. A large mass should contract to a still higher density—how far, no one can yet say. The Sun should have a good ten billion years to go before it begins to fail. Meanwhile as it grows more luminous, the Earth should gradually grow warmer—at the rate of about 1° Fahrenheit in 100 million years.

Finally, where did the carbon, in the Sun,—and also the oxygen and heavier atoms—come from? There is nothing in the reactions sketched above which can form them, and the careful studies of von Weizsäcker and Bethe have found no chance of the production of more than the merest traces by any side-reactions. Yet present evidence indicates that nearly two-thirds of the Sun is composed of such heavy atoms—for, if there were fewer of them and more helium, the molecular weight would be less, and the internal temperature too low to start the carbon-chain running.

It seems necessary to assume that they are *older than the stars*—constituents of the primitive matter of which these were formed. Von Weizsäcker has suggested—in accordance with certain forms of the theory of the expanding universe—that at some remote time the matter in the universe, or a great part of it, was concentrated into a vastly smaller compass than at present, or was much hotter than the inside of the hottest stars are now; but this is highly speculative, though highly interesting.

Another and more practical riddle is, What have huge stars like Y Cygni been doing throughout the 2000 million years or so since the universe fairly started to expand? Such a star is spending its store of energy at least five hundred times faster, in proportion to the total supply, than is the Sun. The transformation of the whole mass from hydrogen to helium would keep it going, at its present rate, for only about 200 million years. Whether this means that these massive stars have begun to shine rather late in the history of the Galaxy, or that, after all, they have still greater stores of energy to draw on, in ways as yet unknown, must be left to the future to determine. But it is reasonable to suppose that, if still more massive stars, which would be far brighter than any now known, had once existed, they would have burned themselves out by this time—so that the question with which we started can be at least tentatively answered.

Polar Compounds for Wetting Agents in the Paper Industry.—"New Surface-Active Chemicals," a discussion of wetting agents and their uses in the paper industry, was the subject of a paper presented by B. G. WILKES and H. F. ROBERTSON, of Mellon Institute of Industrial Research, at the Annual Meeting of the Technical Association of the Pulp and Paper Industry, held recently in New York City. Although the paper industry has, perhaps, been more conservative than the textile industry in its utilization of surface-active materials, current research will undoubtedly disclose the manner in which these wetting agents can be most advantageously employed by paper manufacturers and converters. Wetting agents were described as polar compounds, the molecules of which have water-repellent hydrocarbon groups to which are attached other groups possessing a pronounced affinity for water. As examples of these wetting agents, the "Tergitol" penetrants, which are the sodium salts of certain alcohol sulfates, were cited as especially effective. The relative effectiveness of various wetting agents has been determined by measurements of the time required for weighted skeins of cotton yarn to sink when submerged in wetting agent solutions. These tests have demonstrated that a primary polar compound (whose polar grouping is located at the end of the non-polar portion of the molecule) is relatively mediocre in its wetting and penetrating action as compared with a secondary polar compound (whose polar grouping is located away from either end). "Tergitol" penetrant 7 and "Tergitol" penetrant 4 were the most effective of the secondary alkyl wetting agents tested, the relative effectiveness of these two depending upon the conditions under which they are employed. These penetrants have been used successfully in certain branches of the paper industry. They improve the absorptive speed and capacity of such paper materials as towels, blotting paper, and cleansing tissues. Their carefully controlled use should facilitate the more uniform and complete coverage of papers with aqueous casein and other compositions employed by the converter. Pulping, cooking, bleaching, defiberizing, and de-inking are among the operations on paper raw materials in which more rapid wetting and penetration would be achieved through the use of these penetrants.

R. H. O.

CORRELATION OF COUNTER AND ELECTROSCOPE MEASUREMENTS OF COSMIC RADIATION IN THE STRATOSPHERE.

BY

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ABSTRACT.

Comparison of several methods of measuring cosmic-ray intensities in the stratosphere is presented. Assuming the observed intensity distributions at various elevations, the relations between the vertical intensity and that measured by single counters and by electroscopes is developed. It is shown how geometry affects intensities measured with counters. The observations are found to indicate that the radiation at high elevations (0.75 m. water equivalent) is 1.1 ± 0.1 times more ionizing than at lower elevations (4 m. water). This effect is due to the passage of simultaneous shower rays through the instrument, as well as single rays of higher than average specific ionization. It is further shown that low pressure counters measure a quantity statistically proportional to that observed with electroscopes. The differences between high pressure and low pressure counters are discussed.

INTRODUCTION.

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Recent measurements of cosmic-ray intensities in the upper atmosphere have been made with Geiger counters and with electroscopes. Since these two measuring techniques are not identical in operation, a correlation of the methods yields new information regarding the properties of the radiation.

The electroscope integrates the ionization formed along the paths of each ray passing through it. This instrument, therefore, automatically takes account of the contributions due to the rays of higher than average specific ionization, and of that due to the simultaneous traversal of two or more rays from a shower or burst. The instrument measures the total ionization per cc, independently of geometry. Electroscopes have been used by Bower, Millikan and Neher in a series of high altitude measurements of cosmic radiation at various latitudes.[1]

[1] I. S. Bowen, R. A. Millikan, and H. V. Neher, *Phys. Rev.*, **53**, 885 (1938).

Geiger counter technique may be divided into three distinct classes, each with different properties. These are (*a*) single counters with high gas pressure, (*b*) single counters with low gas pressure, and (*c*) coincidence counters.

A high pressure counter will count the number of ionizing events occurring within it, regardless of the size of the event. Such a counter will count once when n simultaneous rays from a shower or burst, or a highly ionizing slow particle, pass through it. Such counters have been used by Korff and Johnson [2] to measure cosmic ray intensities in the stratosphere.

A low pressure counter differs from a high pressure counter in that the probability that it will count is less than unity, and is proportional to the size of the ionizing event. The calculations applicable to this case are given below. Such counters have been used by Korff, Curtiss and Astin [3] in measurements at various latitudes, and have been studied in detail by Cosyns [4] and by Danforth and Ramsey.[5]

The coincidence counter counts once when a particle passes through both counters. High altitude measurements using such devices have been made by Johnson,[6] by Regener and Pfotzer,[7] and by Swann, Locher, and Danforth.[8]

COMPARISON OF HIGH PRESSURE COUNTERS WITH ELECTROSCOPES.

In comparing the intensities recorded by single high pressure counters and electroscopes, it is necessary to consider three factors, (*a*) geometry, (*b*) showers of simultaneous rays, and (*c*) the passage of rays of higher than average specific ionization through the instrument.

Consider an electroscope operating at a high level in the atmosphere, 0.75 meters water equivalent below the top. The angular distribution of the radiation incident upon it at this level has been measured by Swann, Locher and Danforth.[8]

[2] S. A. Korff and T. H. Johnson, *Phys. Rev.*, **55**, 600 (1939) abs.

[3] S. A. Korff, L. F. Curtiss, and A. V. Astin, *Phys. Rev.*, **53**, 14 (1938).

[4] M. Cosyns, *Bull. Roy. Acad. Belg.*, **23**, 960 (1937); *Nature*, **138**, 284 (1936).

[5] W. E. Danforth and W. E. Ramsey, *Phys. Rev.*, **49**, 854 (1936).

[6] T. H. Johnson, *Phys. Rev.*, **54**, 151 (1938).

[7] E. Regener and G. Pfotzer, *Phys. Zeits.*, **35**, 779 (1934); *Nature*, **136**, 718 (1935); G. Pfotzer, *Zeits. f. Phys.*, **102**, 23 (1936).

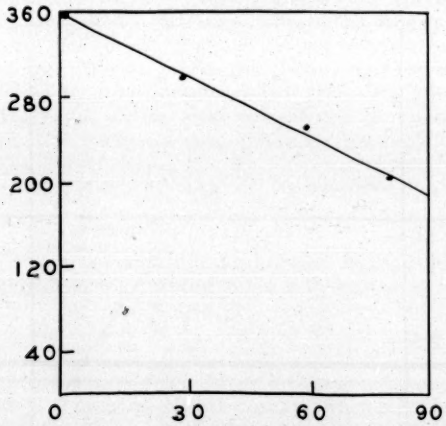
[8] W. F. G. Swann, G. L. Locher, and W. E. Danforth, Nat. Geog. Soc. Contrib. Tech. Papers, Strat. Series, No. 2, pp. 13–25 (1936).

The results of their study are presented in Fig. 1, and may be expressed to a sufficient approximation by the empirical equation

$$j_1 = j_s(1 - \alpha\theta), \tag{1}$$

where j_1 is the intensity at angle θ from the zenith, j_s the

FIG. 1.



Angular distribution of cosmic radiation at a depth of 0.75 meters of water equivalent below the top of the atmosphere. Points are experimental data by Swann, Locher and Danforth; line is empirical representation of eq. (1). Ordinates, counts per minute; abscissæ, degrees from zenith.

intensity incident vertically, and α a constant experimentally found to be 0.28.

An ionization chamber or electroscope operated at that level in the upper atmosphere, where the radiation has the form expressed in (1) will measure an intensity i_s given by:

$$\begin{aligned} i_s &= Aj_s \int_0^{\pi/2} (1 - \alpha\theta) \sin\theta d\theta \\ &= 0.72Aj_s, \end{aligned} \tag{2}$$

where A is a constant.

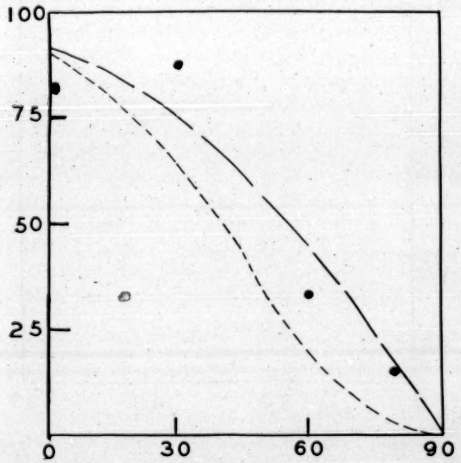
At a lower depth in the atmosphere, 4 meters of water equivalent below the top, the measurements of Swann,

Locher, and Danforth [8] show a quite different distribution (see Fig. 2). It is clear that a distribution of the form

$$j_2 = j \cos^n \theta, \tag{3}$$

where n lies between 1 and 2, will fit the experimental points. As will be seen from the figure, where curves for $n = 1$ and 2

FIG. 2.



Angular distribution of cosmic radiation at depth of 4 meters of water equivalent below the top of the atmosphere. Points are experimental data by Swann, Locher and Danforth. Short dashed line is cosine-square distribution (eq. 3, n 2). Long dashed line is cosine distribution (eq. 3, n 1). Ordinates, counts per minute; abscissæ, degrees from zenith.

are drawn in, the experiments do not determine n with any precision, but fit $n = 1$ somewhat more closely than $n = 2$.

If now the electroscope be operated at this lower level, 4 meters of water equivalent below the top of the atmosphere, the ionization i measured by the instrument will then be given by

$$i = Aj \int_0^{\pi/2} \cos\theta \sin\theta d\theta$$
$$= \tfrac{1}{2}Aj, \tag{4}$$

where the radiation upon it is assumed to be of the form (3) and n is taken as 1. If, however, n be taken as 2, then (4) becomes

$$I = Aj \int_0^{\pi/2} \cos^2\theta \sin\theta d\theta$$
$$= \tfrac{1}{3}Aj. \tag{5}$$

Consider now the single high pressure counters used by Korff and Johnson.[2] In this case four counters were operated side by side, in a horizontal plane, and connected to act as a single counter. We will assume that this arrangement may be approximated by a horizontal sensitive area. At high levels ($0.75m \cdot H_2O$), this arrangement will respond to radiation of the distribution (1) by counting at a rate c_s given by:

$$c_s = Bj_s \int_0^{\pi/2} (1 - \alpha\theta) \cos\theta \sin\theta d\theta$$
$$= 0.36Bj_s, \tag{6}$$

where B is another constant. At the lower depth, 4 meters of water equivalent, the counting rate c will be given by:

$$c = Bj \int_0^{\pi/2} \cos^3\theta \sin\theta d\theta$$
$$= \tfrac{1}{4}Bj \tag{7}$$

for radiation of form (3) where n is 2, and when n is 1 by:

$$c = Bj \int_0^{\pi/2} \cos^2\theta \sin\theta d\theta$$
$$= \tfrac{1}{3}Bj. \tag{8}$$

Equations (2, 4, 5, 6, 7, and 8) permit the evaluation of the following relations between i, j, and c, at the two levels and for the two distributions given in (3).

$n = 1$

(cos θ distribution) $\quad i_s/i = 1.44j_s/j \tag{9}$

$$= 1.33c_s/c. \tag{10}$$

$n = 2$

(cos$^2\theta$ distribution) $\quad i_s/i = 2.15j_s/j \tag{11}$

$$= 1.50c_s/c. \tag{12}$$

Here (9) and (11) represent the relations of the vertical to the total intensities at the two elevations for the various distributions of the intensity at the lower level. Further, (10) and (12) represent the geometrical factor which must be applied to the single high pressure counters arranged in a horizontal sensitive area, in order to permit comparison with the electroscope intensities at the two elevations.

With the aid of these relations, we may now examine the observed intensity ratios, and see whether agreement with the calculations may be effected. The following determinations of the ratios have been carried out experimentally, at approximately the same geomagnetic latitude:

Instrument.	Observers.	Reference.	Quantity.	Amount.
Electroscope.....	Bowen, Millikan and Neher	1	i_s/i	6.4
Round single counter..	Regener and Pfotzer	7	i_s/i	6.7
Flat single counter....	Korff and Johnson	2	c_s/c	4.1
Coincidence counter...	Johnson	6	j_s/j	3.7
Coincidence counter...	Regener and Pfotzer	7	j_s/j	3.7
Coincidence counter...	Pfotzer	7	j_s/j	3.3

Consideration of the ratios of the experimentally determined quantities listed above shows that the observed $i_s/i = 1.56$ to $1.63 c_s/c$. This we may compare with the calculated values between 1.33 and 1.50. From this comparison we may conclude that the factor by which the ionization increases as compared to that by which the counting rate increases, is greater than can be explained on the basis of geometry alone. The difference is most probably due to (*a*) simultaneous rays passing through the instrument, and (*b*) rays whose average specific ionization is slightly higher at the greater altitudes than it is at the lower levels. Another way of stating this conclusion is that on the average an "event" in a counter at high elevations is accompanied by 1.05 to 1.20 times as much ionization as accompanies the event at the lower level.

Comparing the observed values of j_s/j with those of i_s/i, we find a range of between 2.02 and 1.74. This we may compare with a range between 2.15 and 1.44 calculated. It is evident that the calculated ratio is quite sensitive to the distribution at

the lower (4 meter) level. The experiments indicate a distribution of the intensity at this level between a *cosine* and a *cosine-squared* form, a conclusion which is entirely consistent with the angular distribution measurements made by Swann, Locher and Danforth [8] at this elevation.

COMPARISON OF HIGH AND LOW PRESSURE COUNTERS.

It has been shown by Danforth and Ramsey [5] and by Cosyns [4] that the probability that a counter will discharge is equal to the probability that an ion will be formed in the counter. This probability k is given by:

$$k = 1 - e^{-snlp/p_0}, \tag{13}$$

where s is the specific ionization at pressure p_0 characteristic of the gas used and of the velocity of the particle passing through it, n is the number of particles simultaneously passing through the counter, l is the path through the counter, and p is the pressure of the gas in the counter. In the case of a high pressure counter, p is large and k is substantially equal to 1. Hence, it is practically certain that the counter will discharge every time a particle passes through it. Thus, for example, a counter filled with argon at 15 cms. pressure is a "high pressure" counter; n being supposed 1, l being taken as 2 cms., and s for cosmic-rays being 29 ions [4] per cm. at 760 cms. pressure, p being 1/5 atmosphere, k will be 0.99999.

With a low pressure counter, k is appreciably smaller than unity. The relation (13) may then be expanded in a series, and for small values of the exponent the higher terms may be neglected. We then obtain:

$$k = snlp/p_0. \tag{14}$$

From (14) it follows that if a shower of n electrons passes through a low pressure counter, the probability of the counter discharging is n times what it would be if a single particle passed through it. Further, the probability k is proportional to the specific ionization s of the particle passing through it. Thus, for example, a counter filled with hydrogen at 2 cms. pressure, is a "low pressure" counter; if l be taken as 1 cm., s is 6.0 per atmosphere,[4, 5] p is 2/76 atmosphere, n taken as 1,

then k will be 0.13 from (13) or will be 0.15 from (14). It is evident that the probability that this counter will discharge will be materially affected by the ionizing power of the radiation passing through it, for if the ionizing power be doubled, as if an electron pair passed through the counter, k from (14) will be 0.30. It is obvious that approximation (14) breaks down for large values of ionizing power (n or s). Hence the low pressure counter will not yield counting rates proportional to the electroscope reading if the radiation contains abundant particles of very high specific ionization.

The factor (14) if multiplied by the number of rays (or ray groups) per unit time passing through the instrument, is equal to the amount of ionization which is measured by an electroscope. Hence an ideal low pressure counter (one for which eq. 14 holds rigorously) behaves statistically in the same manner as an electroscope, and has a preferential response to showers and to rays of high specific ionization. The experimental consequence of this is that electroscopes and ideal low pressure counters will measure the same increments in the total cosmic radiation regardless of geometry, if they are carried through the same change in elevation. However, the "ideal" condition is not attainable in practice when specific ionizations in excess of five times that of a cosmic-ray electron are present, since to measure higher ionizations proportionally would require gas pressures inside the counter of less than 1 cm. H_2. Hence the use of low pressure counters for measurements of total ionization is limited to those cases for which the ionization associated with a single count is not more than five times that produced by a fast electron.

Experimentally, cosmic-ray intensities have been measured by low pressure counters by Korff, Curtiss, and Astin [3] and by Cosyns.[4] The curve of the increase of cosmic-ray intensity with altitude obtained with these counters, was found to agree within the experimental error with that found on the electroscope flights made by Millikan and his collaborators. Although the general impression exists that counters and electroscopes measure essentially different quantities, the above argument shows why an approximate agreement between the two measurements cited was actually observed.

COMPARISON OF EARLIER ELECTROSCOPE AND INTEGRATED COUNTER MEASUREMENTS.

On the Fordney-Settle flight, electroscope measurements were made by Bowen, Millikan, and Neher [9] and also by Compton and Stephenson,[10] which differ from those described above. The ionization ratio observed in this flight was higher than that found with small balloons, i_s/i being 8 instead of 6.4. On the National Geographic U. S. Army Air Corps stratosphere flight of Explorer II, counter measurements were made by Swann, Locher. and Danforth.[8] Coincidences were counted in various directions, and all were graphically integrated to obtain a measure of the total radiation. The value of i_s/i obtained in this manner was substantially in agreement with the figure found by Millikan in the Fordney-Settle flight.

No entirely satisfactory explanation of the discrepancy between the figures thus obtained, and those found with the small balloons has yet been advanced. Evidently, however, the radiation conditions were different inside the gondola from those outside. The counters were shielded by a set of guard counters, so placed and connected that if a shower from the side set off the coincidence train, nothing would be recorded. A duplicate set of counters without this screen did not show any very different counting rate. It is clear that a complicated process affects these observations, since explanations based on simple scattering seem inadequate to explain both the electroscope and the counter data.

The high altitude measurements referred to above were partly supported by the Carnegie Institution of Washington. The authors are especially indebted to W. F. G. Swann for helpful discussions.

[9] I. S. Bowen, R. A. Millikan, and H. V. Neher, *Phys. Rev.*, **46**, 641 (1934).
[10] A. H. Compton and R. J. Stephenson, *Phys. Rev.*, **45**, 441 (1934).

Tunnel Paved with Concrete Blocks.—(*Engineering News Record*, Vol. 122, No. 15.) A new type of tunnel pavement in the form of precast concrete blocks is installed in the 178th St. underground vehicle approach to the George Washington Bridge in New York. The blocks, each $11\frac{3}{4}$ in. square and 4 in. thick, are laid with poured asphalt joints on a bituminous mastic cushion. The paving, being laid in the 2350 ft. cut and cover tunnel cutting across the upper end of Manhattan, is part of the Port of New York Authority's current program of extending the New York approach facilities, curtailed at the time the bridge was opened in 1931 pending increased traffic. Though the tunnel structure was built several years ago, it was never finished for use. Anticipated World's Fair traffic this year prompted the present plans for completion. Some form of removable block pavement in tunnels is considered necessary by the Port Authority because of the possibility of excess wear from close tracking of heavy traffic. Such removable blocks permit local repairs and replacements to be made quickly and easily with minimum interruption to traffic. The authority now has three different types of paving in three tunnels: granite block in the Holland; de-aired brick in the Lincoln; and the new type concrete block at George Washington Bridge.

R. H. O.

ELECTROLYTIC DEVELOPMENT OF THE LATENT IMAGE.*

BY

RICHARD S. MORSE.

INTRODUCTION.

Since the early days of photography, various workers have investigated the effects of electric currents on photographic materials. Daguerre [1] himself endeavored to increase the *sensitivity* of his iodized metal plate by the passage of a weak current through it and this idea appears to have been studied rather carefully by other workers [2] during the middle of the last century. In 1878, Boll [3] claimed success in his work of increasing the sensitivity of collodion plates by such methods.

Russell [4] and others [5] have studied the *formation* of photographic images caused by contact with various metals. Most of the experimental work has been carried out in aqueous solutions, and it is generally believed that developable images are produced in this manner by an ionic replacement process.

Banks [6] appears to have been the first actually to develop a photographic image by electrolytic action. A silvered copper plate was coated with emulsion and, after exposure, was brought into contact with a zinc plate. Upon electrically connecting the two plates, and placing them in solution, a visible image was produced. This type of development has been explained on the basis that silver bromide can be preferentially reduced by nascent hydrogen in the neighbor-

* Communication No. 729 from the Kodak Research Laboratories.

[1] J. M. Eder, "Handbuch d. Photographie," 3rd edition, Vol. I, Part II, p. 421 (1906).

[2] Roggerson, *Horns Phot. J.*, **10**, 95 (1858).

[3] Boll, *Phot. Mitteilungen*, **15**, 209 (1878).

[4] W. J. Russell, *Proc. Roy. Soc.*, **64**, 409 (1898).

[5] J. Sperber, "Eders Jahrbuch d. Photographie," p. 501 (1899). K. Schaum, *Z. f. wiss. Phot.*, **2**, 427 (1904). S. Suzuki and K. Kawadi, *Nagasaki Ann.*, pp. 189–93 (1925).

[6] E. Banks, *Brit. J. Phot.*, **42**, 648 (1895); *Ibid.*, **43**, 677 (1896).

hood of the latent image. These results might perhaps also be explained by a deposition of silver ions during electrolysis.

Fuchs [7] and others [8] have described the action of an external electromotive force as an aid in the development of photosensitive materials. For example, photographic paper which has been exposed may be placed between electrodes, one being copper, and the other zinc. If these two electrodes are placed in solutions of chrome alum and sodium sulfate, respectively, and a potential of 0.8 volt with a current of about 20 milliamperes is employed, the normal latent image may be developed. The formation of chromous sulfate at the cathode has been suggested as the developing agent in this case, and, according to Seyewetz, this substance can serve as a chemical developer. It is conceivable, however, that the image is at least partially produced merely by migration of silver ions during electrolysis.

NORMAL PHYSICAL DEVELOPMENT.

Common physical developers usually contain an excess of silver nitrate and some suitable reducing agent such as metol.[9] The silver salt, upon being reduced to silver, is deposited about the latent image which serves as deposition centers. Under proper conditions, development of this type produces images of finer grain, and for such work the use of paraphenylenediamine as a reducer has been suggested.[10]

Under proper conditions, other silver salts may be employed and the use of silver chloride with sodium sulfite, and silver sulfite alone has been treated extensively by Lüppo-Cramer.[11]

As originally shown by Young [12] in 1858, it is possible to

[7] E. Fuchs, *Phot. Ind.*, **28**, 927–28 (1930).

[8] J. Rzymkowski, *Phot. Ind.*, **35**, 453–54 (1937). E. Kellner and K. Bennewitz, *Z. f. wiss. Phot.*, **33**, 212–33 (1935).

[9] E. Valenta, *Camera (Luzern)*, **1**, 109–110 (1922). F. Bürki, *Schweiz. Phot. Zeit.*, **29**, 338–39 (1927). R. E. Owen, *Phot. J.*, **53**, 278–80 (1929). A. F. Odell, *Camera (Phila.)*, **46**, 217 (1933); *Ibid.*, **54**, 145–54 (1937).

[10] A. and L. Lumière and A. Seyewetz, *Bull. Soc. Franç. Phot.*, **20**, 422 (1904); *Sci. Ind. Phot.*, **7**, 107 (1927).

[11] Lüppo-Cramer, *Phot. Korr.*, pp. 280–82, No. 512 (1903); *Ibid.*, pp. 570–74, No. 614 (1911); *Ibid.*, pp. 402–06, No. 649 (1914).

[12] H. Young, *Phot. News*, **1**, 166 (1858).

develop wet collodion plates physically after fixation. Kogelman [13] and others [14] have shown that this is also true of gelatin emulsions of the silver halide type.

In addition to physical development with various silver salts, it is also possible to form images of other metals and the use of mercury salts in a physical developer was demonstrated by Carey Lea [15] in 1865.

Other workers [16] using, for example, solutions of mercuric bromide, sodium sulfite and metol have produced mercury images after fixation.

DEVELOPMENT BY METALLIC CONTACT.

Although in the method of development to be described, no external electromotive force is required, the action may be termed "electrolytic development" for want of a better description.

It has been found that if a photographic material of the silver halide type is exposed and subsequently bathed in an ammonia solution containing a trace of a suitable metallic salt, a visible image may then be produced by placing the emulsion in *intimate contact* with a clean copper plate. As a matter of fact, it is possible to develop such a latent image by bathing in ammonia alone and then applying the copper plate. In the case of pre-fixation development, without the addition of a metallic salt it appears to be impossible, however, to produce a dense image free from fog, or to produce any image by post-fixation development.

The following formula is representative of the solutions used:

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[13] F. Kogelmann, "Die Isolierung der Substanz des latenten photographischen Bildes," Dissertation, Graz, 1894.

[14] Sterry, *Photography*, **10**, 260 (1898). R. Neuhauss, *Phot. Rund.*, **12**, 257–58 (1898); *Ibid.*, **18**, 134 (1904). A. and L. Lumière and A. Seyewetz, *Bull. Soc. Franç. Phot.*, **2**, 264 (1911); *Compt. rend.*, **179**, 14 (1924); *Ibid.*, **178**, 1765 (1924); *Bull. Assoc. Belge Phot.*, **46**, 74 (1924); *Brit. J. Phot.*, **71**, 384–85 (1924) Lüppo-Cramer, *Phot. Ind.*, **61**, 780 (1924). H. Leffmann, *Brit. J. Phot.*, **71**, 49 (1924). C. de Albroit, *Il Corr. Fotografico*, **23**, 267 (1926).

[15] Carey Lea, "Eders Handbuch d. Photographie," 2nd edition, Vol. II, Part I, p. 58 (1895).

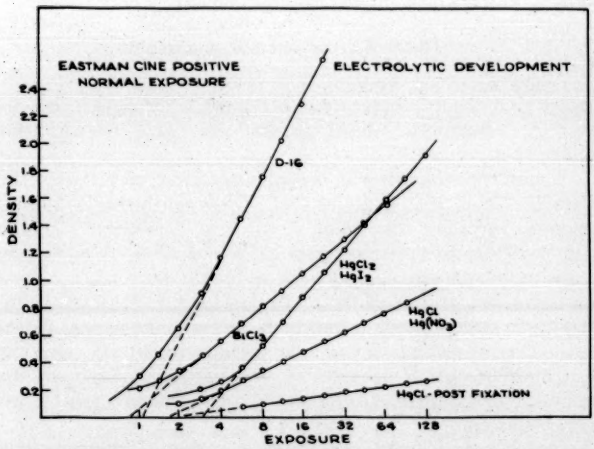
[16] Lüppo-Cramer, *Phot. Ind.*, p. 401, No. 25 (1917).

NH_4OH	40.0 cc.
Formaldehyde	5.0 cc.
Water	200.0 cc.
$HgCl_2$	0.5 gram

The formaldehyde serves only to harden the gelatin in the alkaline bath and apparently does not enter into the reaction.

In developing film according to this method, images are obtained which visually appear similar to those resulting from

FIG. 1.



A comparison of photographic images obtained by normal *chemical development*, and "electrolytic development." In the latter cases, curves are shown for images produced after bathing in ammonia solutions containing various ions.

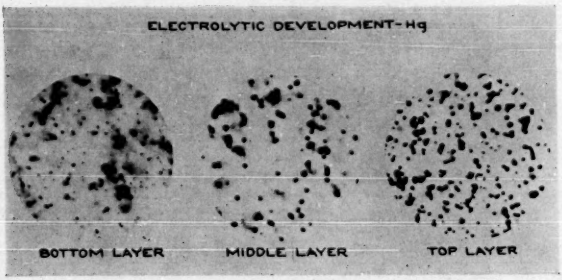
normal chemical development. In general, higher fog values are encountered and both black and brown images have been noticed depending upon the particular metallic salt present in solution.

Eastman Cine Positive film which had received normal exposure in the standard Type IIb sensitometer was developed electrolytically and characteristic curves obtained as shown in Fig. 1. As a comparison, the curve for the same material

developed in D-16 developer is included. It can be seen that comparable inertia speeds are found.

An examination of the developed grain structure at various depths throughout the emulsion indicates that such images are not of the surface type as is the case with the usual physical development (Fig. 2). The character of the images formed with different types of solutions is illustrated in Fig. 3, and it is seen that the grains seem to give the appearance of having been produced by deposition. Salts of silver, antimony, and arsenic form images of high density but only with excessive fog. The use of potassium bromide, or antifoggants, such as 6-nitro-benziminazole, have little effect on these results.

FIG. 2.



Enlargements of images produced by electrolytic development. (2500 ×)

After a certain length of time has passed, for a given solution, both speed and gamma remain independent of the time of bathing and of contact with the plate. In all cases, it is highly essential that the plate be clean and that the emulsion be pressed tightly on the surface.

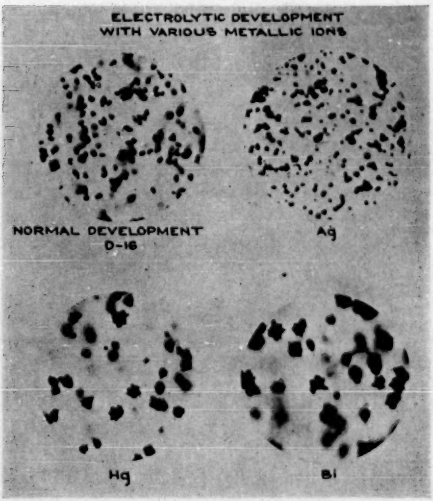
POST-FIXATION DEVELOPMENT.

Investigations have been made which show that post-fixation development may also be carried out according to the procedure just described. Strips of exposed Eastman Cine Positive film were fixed for ten hours, in a solution of 20 per cent. sodium sulfite, much less bleaching of the image

being obtained with this material as compared with the more customary sodium thiosulfate.

The characteristic *H* and *D* curve obtained with post-fixation development of this type, using a trace of mercurous chloride in solution, is given in Fig. 1. It is interesting to note that the inertia speed is nearly half that found with normal

FIG. 3.



Enlargements of images produced by normal chemical development and by electrolytic development using silver, mercury, and bismuth ions in the ammoniacal solution. (2500 ×)

chemical development, a higher value than might be expected from other non-orthodox development methods.

THEORETICAL CONSIDERATIONS.

There does not appear to be any obvious explanation of the part played by the metallic salts in development of this type. In most cases, the salts used are only very slightly soluble in the solution and have very low dissociation constants.

Analyses show that in all cases the image is essentially silver. In the solutions of ammonia used, a fairly high concentration of silver and bromide ions could be expected and by a replacement process the silver would tend to come out of solution on the formation of Cu^{+} ions.

This reaction, however, will not take place in solution, even over periods of several hours, unless the emulsion is in close physical contact with the copper surface.

It appears, therefore, that a form of couple is produced between the latent image and the copper, and this reaction is furthered by the presence of other metallic ions, such as Bi^{+++}, Hg^{+}, Sb^{+++}, Hg^{++}, etc. Possibly it is only under conditions of close contact between the emulsion and plate that cuprous ions are present in sufficient concentration to promote development. It is interesting to note that mercurous and mercuric ions are the most satisfactory in this respect. Metallic copper may also be considered as a depolarizer, the reduction potential being maintained according to such reactions as:

$$Cu^{0} + Hg^{+} \rightleftharpoons Hg^{++}.$$

A suggested explanation of electrolytic development after fixation can be offered more easily than in the case when silver halide is present. Although mercurous chloride has a low dissociation constant, it is very slightly soluble in ammonia and probably serves as a source of mercurous ions which may be present at least partially in complex form. The copper plate produces Cu^{+} ions which in the complex form are capable of reducing the mercurous ions to metallic mercury. On coming out of solution, the mercury forms a visible image, the silver or silver plus silver sulfide specks of the latent image serving as deposition centers.

Four New and Valuable Products Made from Lignin in Wood Waste.—By adding hydrogen to lignin—chemistry's problem child—scientists of the U. S. Forest Service's Forest Products Laboratory at Madison, Wis., have learned how to convert this waste product of wood into products that bear promise of being valuable raw materials with many uses. One is a well-known product—methanol, or wood alcohol. Four others had not been previously discovered, although one of the group was described as theoretically possible by a German scientist. The properties of these new substances are such as to suggest their use as wood preservatives, fungicides, insecticides, adhesives, solvents and plastic materials. The co-discoverers, Dr. E. C. Sherrard and Dr. E. E. Harris describe the first new substance as parapropylcyclohexanol, valuable as a solvent for organic gums and resins, and oils used in lacquers. It has value as a preservative, and is about as repellent to insects as creosote. The second and third substances, described as 4-propyl, 1, 2-dihydroxycyclohexane and 3-p-hydroxycyclohexylpropanol, are thick liquids which become solid after standing a long while. Both may be made into plastic materials. The fourth substance is crystalline and unnamed, as the discoverers have not yet determined the positions of the carbon, hydrogen, and oxygen atoms of which it is composed. The empirical formula, or number of atoms regardless of structure, of the substance is $C_{18}H_{32}O_3$. It has properties that make it valuable as a lacquer ingredient and because of its water resistance, as a cement or adhesive for wood, paper, metal, and other materials. It also may be used as a plastic material. Because of its complex chemical nature, lignin in its natural state has baffled scientists. By submitting it to the hydrogenation process the Forest Service scientists changed its chemical nature so that it could be broken down into component parts. In the laboratory tests the hydrogen atoms were added to a solution of purified lignin by means of heat and pressure and the use of a catalyst—copper chromium oxide. Under this treatment the dirty brown lignin solution changed to a thick, sticky, and colorless fluid. The catalyst was removed by the use of a centrifuge. The residue was then distilled, or fractioned, to create the wood alcohol and the four new substances.

R. H. O.

SYNTHESIS OF ORGANIC COMPOUNDS CONTAINING RADIOACTIVE SULFUR.

BY

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Artificial radioactive elements have found extensive application in chemistry, physical chemistry, and especially in biochemistry, as indicators in the study of metabolic processes. For example, organic compounds containing P^{32} or C^{11} have been synthesized in the animal body,[1] in plants,[2] and *in vitro*.[3, 4] Little attention has been given to S^{35} apparently on account of its very soft beta rays which make quantitative measurements difficult. Recently Miss R. G. Franklin, of this Foundation, has reported [5] on the biological synthesis of glutathione* [6] by yeast grown in a medium containing MgS^*O_4. The author has now succeeded in synthesizing *in vitro* two compounds containing radioactive sulfur, 4,4′-dinitrodiphenyl disulfide* and *p*-nitrobenzenesulfonyl chloride*, which are intermediates in the synthesis of the biologically important sulfanilamide*.

S^{35} was obtained as a by-product in the bombardment of CCl_4 with neutrons accelerated by the Cyclotron of the Biochemical Research Foundation, located at the Bartol Research Foundation. The S^{35} was then isolated, after the addition of ordinary sulfur, by distilling off the CCl_4. Only 55 mg. of S* with an activity of 345 counts per minute for 1 mg. were available. This sample contained about 10 per cent. of carbonaceous material, due to an accident in distilling off the

[1] Hevesy, *Enzymologia*, **5**, 138 (1938).

[2] Ruben, Hassid and Kamen, *Jour. Amer. Chem. Soc.*, **61**, 661 (1939).

[3] Chargaff, *ibid.*, **60**, 1700 (1938).

[4] Long, *ibid.*, **61**, 570 (1939).

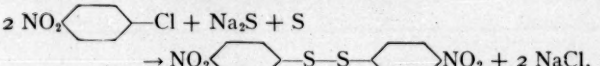
[5] Franklin, *Science*, **89**, 298 (1939); see also JOUR. FRANK. INST., **227**, 722 (1939).

[6] Elements and compounds containing radioactive atoms are identified with an asterisk, such as P*, S*, or C^*O_2.

CCl_4; the impurities were, however, eliminated during the course of the synthetic work. Thus, the activity measurements, which were carried out with the Geiger counter described by Franklin,[5] had to be compared with the measurements of a sample of S*, which had been subjected to a recrystallization from CS_2; this S* gave 405 counts per minute for 1 mg.

Because of the small amount of S* available, it became necessary to use microtechniques [7] both for the synthesis and for the subsequent analysis. Identical syntheses were carried out on the same scale, using ordinary sulfur instead of S*; this permitted an efficient comparison of yields, physical constants, and chemical characteristics of the compounds in the two cases.

4,4'-DINITRODIPHENYL DISULFIDE*.



The procedure of Hodgson and Wilson [8] was followed on a centigram scale with 50 mg. S*, and 50 mg. S for comparison. Since the equivalent amounts of Na_2S added in this step contained only inactive sulfur, the radioactivity of the S* was reduced to 50 per cent. of the original value. The amount of crude material obtained was 100 mg.* (65 per cent. yield) and 104 mg. (67.5 per cent. yield) respectively. On recrystallization from acetone and glacial acetic acid three fractions of crystals were separated, the second of which according to the data given in Table I was the most nearly pure and the most active. The micro Beilstein test for halogens [7] was negative in all fractions.

The melting points found in the literature for this compound varied over a wide range. Using the micro melting point procedure on Kofler's hot stage [7] the following behavior of the compound on heating was observed: crystals, apparently of the tetragonal system, started to melt at 134° C.; on holding the temperature slightly above this melting point needle-like

[7] Alber, JOUR. FRANK. INST., **226**, 813 (1938); Alber and Harand, *ibid.*, **224**, 729 (1937).

[8] Hodgson and Wilson, *J. Chem. Soc.*, 1925, p. 440.

crystals grew out from the melt and gave, on further heating, a melting point of 164 to 165° C. The remaining crystals reached their melting point at 178 to 179° C.; all determinations were carried out by raising the temperature at the rate of 4 degrees C. per minute. It is probable that three crystal modifications were present, which would account for the varying melting points cited in the literature, e.g., 170 and 180° C.[8, 9]

Radioactivity Measurements.—The organic compound was dissolved in acetone and evaporated in small portions in a nickel boat, until 3.30 mg., corresponding to 0.68 mg. S and to 0.34 mg. S*, were deposited as evenly as possible.[10] The counts per minute for the stated amount of 4,4'-dinitrodiphenyl disulfide* are recorded in Table I. The ratio between the

TABLE I.

4,4'-Dinitrodiphenyl disulfide.

Fraction on Recrystallization	Micro M.P. in ° C.	N—Found (Calc. 9.08%)	S—Found (Calc. 20.8%)	Counts per Minute for 3.30 Mg.
First*.....	134, 164	9.59%	—	127
Second*.....	140, 164, 178–179	9.18%	20.9%	139
Third*.....	134, 163–164, 176–178	9.01%	—	87
Inactive.....	134, 164–165, 178–179	9.12%	20.9%	none

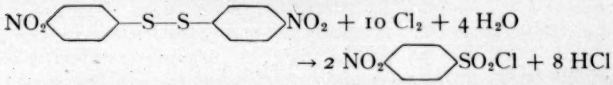
radioactive and ordinary sulfur in the original S*-sample remains unchanged in the organic molecule obtained by synthesis, as seen from a comparison between the second fraction* and S*. For the activity measurements and comparisons, the latter was freed of carbonaceous material by recrystallization from CS_2, then redissolved and deposited as a thin film in a nickel boat by evaporation. The ratio of the observed activities between 3.30 mg. 4,4'-dinitrodiphenyl disulfide* and 0.68 mg. of the above mentioned S* is 1 : 1.97

[9] Blanksma, *Rec. trav. chim.*, **20**, 141 (1901); Zincke and Lenhardt, *Ann.*, **400**, 2 (1913).

[10] It is realized that the radioactivity measurements would have been more accurate if the S* of the organic compound had been transformed into BaS^*O_4 first. Thus, the results would have been comparable. Because of the necessity of conserving material for the succeeding steps in the synthesis, the conversion into BaS^*O_4 was omitted. Therefore, the measurements cannot be as accurate and as quantitative as some of the results in this investigation may indicate.

(139 : 274 counts per minute) which is in good agreement with the calculated ratio of 1 : 2 of their equivalent S* contents. On repeating the experiment after one week only 0.34 mg. S* were used; the observed ratio of 1 : 1.01 (119 : 120 counts per minute) is the same as the calculated one of 1 : 1.

p-NITROBENZENESULFONYL CHLORIDE*.



Since only 20 mg. of 4,4′-dinitrodiphenyl disulfide* remained after the above tests, all fractions were combined. The procedure of Loudon and Shulman [11] was followed on a milligram scale. 20 mg.* and 17 mg., respectively, of the disulfide yielded 99 per cent. of radioactive and 98 per cent. of ordinary crude material. On recrystallization from benzene-petroleum ether a yield of only 52 per cent. pure compound* was obtained, as compared with the more favorable yield of 80 per cent. of the inactive compound. This low yield of the active compound may be attributed mainly to the incorporation of the impure first and third fractions, but was of minor consideration in the present investigation where the efforts were concentrated on obtaining chemically pure and highly radioactive compounds rather than perfect yields.

The micro melting point of 79° C. on the Kofler hot stage was slightly lower than the capillary melting point of 80° C. reported by Bell.[12] Both active and inactive compounds gave a positive micro Beilstein test.

Radioactivity Measurements.—2.28 mg. *p*-nitrobenzenesulfonyl chloride* corresponding to 0.33 mg. S or 0.165 mg. S* were distributed in a nickel boat as described above, and compared with 0.33 mg. of purified S*; the observed ratio between the activities of these two samples was 1 : 2.4 (50 : 120 counts per minute) instead of the calculated ratio of 1 : 2 between their S*-contents.

2.28 mg. *p*-nitrobenzenesulfonyl chloride*, i.e., 0.165 mg. S*, were compared with 3.30 mg. 4,4′-dinitrodiphenyl

[11] Loudon and Shulman, *Jour. Chem. Soc.*, 1938, p. 1618.

[12] Bell, *ibid.*, 1928, p. 2770.

TABLE II.
p-Nitrobenzenesulfonyl chloride.

Sample	Micro M.P. in ° C.	Semi-quantitative Estimation (7)	N—Found (Calc. 6.32%).	S—Found (Calc. 14.47%)	Counts per Minute for 2.28 Mg. Sample
Active*	78.5–79	N = 5–8% S = 10–15% Cl = 15–20%	6.38%	—	50
Inactive	79	—	6.34%	14.55%	none

disulfide*, i.e., 0.34 mg. S*. The calculated ratio of 1 : 2.06 for their S*-contents compared favorably with the observed ratio of 1 : 2.38 (50 : 119 counts per minute) for their activities.

The Physics Department of the Biochemical Research Foundation, under the direction of Dr. A. J. Allen, supplied the sample of S* and carried out the radioactivity measurements; their coöperation is deeply appreciated.

Everyman's Meat.—(*Industrial Bulletin of Arthur D. Little, Inc.*, No. 146.) A special favorite of the privileged gourmet, tender juicy steak, may become plentiful by an improvement that makes any old beef "tender." To lend an Arabian Nights touch, the new delicacy is brought forth by the servants of a lamp. Broiled "Tenderay" Steak Kroger was served recently at a coming out party given by Westinghouse, Kroger Food Foundation, and Mellon Institute. Even the guests from the meat packers found it hard to believe that the steak came from a tough steer sacrificed only three days earlier. Sponsors of the new process claimed that meat for steaks, roasts, etc., can thus be raised one or more grades, and promise strong backing for general introduction of the method. Much of the toughness of beef is due to the collagen that binds the meat fibers together. By an age-old practice, skilled chefs hang their best beef for a long period of time until natural enzymes soften the collagen and the meat becomes tender. By the new method the meat is hung at higher temperatures, and the enzymes act more rapidly. It is exposed to ultra-violet rays from the Westinghouse Sterilamp, which prevent unattractive mold growths and losses due to them. The lamp also creates a mild bit of ozone, sufficient to protect the shadow areas as the rays do the illuminated portion. In practice it is found necessary to follow an established method to avoid rancidity and other difficulties, with sufficient lamps, properly placed and maintained. Costs incident to the method are said to be low in comparison with the grade improvement obtained.

R. H. O.

THE OUTLOOK IN FLUID MECHANICS.

BY

WILLIAM FREDERICK DURAND, Ph.D., LL.D.

It may be permitted to doubt whether the public at large has any adequately realizing sense of the part which fluid mechanics plays, not only in our daily lives, but throughout the entire domain of Nature. Matter as we know it is either solid or fluid (using the latter term to include liquids, gases and vapors). Or otherwise, we may say that matter is comprised of aggregates of molecules in which there is either relative immobility or relative mobility of the translational movement of the molecules relative to each other. The two conditions shade into each other. Thus many solids such as lead, copper, resins, etc. will flow under suitable conditions as to pressure and time. Broadly speaking, however, the terms solid and fluid represent two categories, in one or the other of which, matter, as we commonly find it, is readily classed.

But from the very fact of their molecular mobility, fluids, if they are to play what we may term a controlled part in Nature, must be subject to some type or form of constraint by solid boundaries. Without such constraint, fluids on the Earth would, under gravitation, stratify according to specific gravity in the form of a series of layers with equipotential gravitational surfaces for their boundaries. But in order to take part in the phenomena of Nature, there must be resistant boundaries, containers, channels, guiding surfaces; and these latter must be of matter in the form we call solid. And thus we find a vast interplay in Nature of solids and fluids, for the most part in relative motion, one with the other.

Thus the flow of rivers and streams in their boundaries, the percolation of water through the soil, the circulation of the blood in our arteries and veins and more broadly the movement of nutrient and of scavenging media throughout the entire domain of organic life; the flight of the insect, the bird and the airplane; the movement of a ship in the water or of a fish

in the depths, the degredation of our soil and its carriage away to the sea, the winds and the weather; these are all, in major degree, varied expressions of the laws of fluid mechanics. From these major phenomena of Nature through to such a trivial incident as the stirring of our coffee with a spoon, the more evenly to distribute the sweetened solution through the volume of the cup, everywhere we find fluids and solids in reactive contact, usually in relative motion, and everywhere in this domain, the laws of fluid mechanics must control.

The peculiar relation between a fluid and a solid body moving through it must have early engaged the interest and attention of the philosophers even of prehistoric times. Perhaps the earliest measurably explicit statements were those made by Aristotle in attempting to show that a vacuum cannot exist. He assumed that the motion of a body, as through the air, was due to the action of a continuous force applied to the body and by direct contact with some other body, in this case the air. And since the projectile moved continuously, it must be continuously acted on by the air through which it moved and hence a vacuum could not exist. He was here chiefly concerned with the argument against the existence of a vacuum and gave but small consideration to the manner in which the air would be able thus to act on the projectile and maintain its motion. These matters he left to the investigation of his successors, giving only two hints, one that the air in closing in violently to fill the vacuum, which would otherwise be left in the wake of the projectile, was able to exercise the push which his theory required. The other, somewhat more vaguely suggested that the air, by virtue of its special fluidity, was able, if once set in motion by the body moving through it, to continue its action on the body. These hypotheses and suggestions of Aristotle seem to have formed the first chapter in the slowly developing body of what we have since come to call Fluid Mechanics.

No attempt will be made to trace historically the growth of this branch of science, interesting as it is and replete as it is with great names from Leonardo da Vinci to those of our own times.

Brief reference must, however, be made to the simplifying assumptions which made possible the application of the varied

and rich resources of mathematics to the behavior of a fluid with idealized characteristics and qualities.

In actual fluids, as we must deal with them in Nature, we recognize two special characteristics to which the names of viscosity and compressibility have been given. We find, moreover, in actual fluids, all degrees of these characteristics—for viscosity all the way from that exhibited in air or light gases to that characteristic of heavy oil or tar in cold weather; for compressibility, all the way from almost negligible amounts as in water and most liquids, to that characteristic of air and gases and vapors in general.

Now it is a common enough feature of mathematical strategy, where a long series of conditions are met with ranging from the very large to the very small, to carry on by hypothesis to the limit, and assume an ideal characterized by zero values. Application of this strategy led immediately to the assumption of an ideal fluid with zero viscosity and zero compressibility. Zero viscosity implies the entire absence of any forces of the nature of a drag or a shear, affecting the movement of one molecule in sliding movement near another. Zero compressibility implies the maintenance of a constant mean molecular separation throughout the fluid under all conditions of pressure and temperature, and hence the maintenance of a constant volume under all conditions of relative movement between solids and fluids.

With this assumption of an ideal fluid and the resources of the mathematical disciplines of differential equations, theory of complex variables, conformal transformation with a little function theory and some simple principles of mechanics, it has been found possible to erect an imposing structure of classical fluid mechanics. It is interesting to note, in passing, that the general direction of approach has been by way of the geometry of fields of flow—mapping of the so-called streamlines through the application of differential equations and conformal transformation. Through the use of these two powerful agencies, applied to various combinations of the three types of basic flow—the parallel flow from infinity, the source-sink flow and the vortex—it has been found possible to determine the geometry of fields of fluid motion of the most varied types. And from this knowledge of the geometry of

the field, there follow, in direct sequence, the field distributions of velocity and of pressure, thus completing the solution.

As beautiful and complete as these solutions are for the assumed ideal fluid, they advance us only part way with reference to the important question of the force reactions between the body and the fluid. Combinations of the infinite flow and of the vortex type of flow do serve to indicate the source of lateral or so-called lift forces and give likewise their measure. No combination, however, gives indications of the source of forces acting in opposition to the motion—resistance or drag forces. Such forces, with ideal fluids, in fact, become zero since, with such an ideal medium, there is no way of providing for transfers of energy between the body and the fluid and, without such transfers, there can be no force of resistance or drag.

When dealing with the dynamic reactions between a solid body and a fluid in relative motion, we are primarily concerned with the two major components of the total force reaction—that parallel to and in opposition to the direction of motion (resistance or drag) and that transverse to the direction of motion (lift). As we have seen, the mechanics of the perfect fluid gives us a measure of the latter (though in terms not always easy of numerical evaluation) while it fails entirely to give any satisfactory account or measure of the former. If, therefore, we are to find some means of relating the measure of this resistance or drag force to the circumstances of the motion, it is clear that we must deal with actual fluids, or at least with some medium idealized in lesser degree than the ideal fluid which has served so admirably for the development of the classical mechanics. As we have seen, the ideal medium is assumed to be incompressible and devoid of viscosity while actual fluids are compressible and have viscosity—both characteristics in widely varying degrees. However, there are many fluids, liquids in particular, in which the compressibility under conditions of ordinary use is very small, while with gases and vapors the response may be large, though often small under the conditions of actual use contemplated. If then we propose to focus on the influence of viscosity on fluid motion, it seems quite permissible to assume a medium and conditions of use for which the compressibility will be small or

negligible. If otherwise we are to focus on the influence of compressibility, it seems reasonable to assume a medium like air, in which the viscosity is at least low, while the effects due to compressibility may become large.

Considering first the effects due to viscosity, we must now make a nearer approach to the phenomena attendant on the relative motion of a fluid and a solid, as, for example, a liquid flowing through a cylindrical pipe. Two types of motion are recognized, (1) The so-called laminar flow characterized by smooth continuous parallel paths for adjacent particles; (2) The so-called turbulent flow characterized by what may, perhaps, best be called, simply irregular motion. In fact the irregularity is so varied and so great that, geometrically, we know very little about it in detail. It is the type of motion so plainly to be seen near the skin of a ship when in motion through smooth surface water. Turbulent water may contain vortices small or large and in the process of growth or decay; but a distinction should be made between vortex motion as such and turbulence. The former is definitely ordered in its geometry and in the laws of its formation and behavior. The latter is simply chaotic, and without geometrical form or pattern.

Fluid movement in general is characterized by turbulent flow—thus the movements of the atmosphere, the flow of rivers between their banks, the flow of water in large pipes. Less commonly do we find cases of laminar flow—the movement of fluids of high viscosity, heavy oils, molten glass, or of water at moderate or low velocity in a tube or channel of small cross section.

If what may be termed the degree of irregularity in the motion is the same in every direction and throughout the flow, the condition is known as isotropic turbulence. Naturally this is the simplest case. If in addition, throughout the flow, there is variation of the degree of turbulence or of a defining dimension, such as Prandtl's "mixing length," the case is vastly more complex and defies analysis unless at least something is known regarding the character of this variation.

Laminar flow, as noted, is characteristic of the conditions which obtain, when the viscosity of the fluid is high or the relative velocity between the solid and the fluid is very low.

We might perhaps say that laminar flow, in its geometric form, seems to be the natural first response to the conditions imposed by the relative motion between the solid and the fluid. With increase in velocity, however, a condition is reached where the relative simplicity of the laminar flow disappears and the motion passes over into the turbulent phase. This transition from laminar to turbulent may involve the entire body of flow so far as affected by the presence of the solid body or surface. Such is the case with flow through a pipe or channel of uniform section. In the case of bodies of variable cross-sectional area, such as an airplane wing, the flow may be laminar up to a certain point or zone, and then, abruptly, become transformed into the turbulent phase.

It may also be noted that for laminar flow the particle paths are quite similar, geometrically, to the lines of flow for an ideal fluid about the given body. This, however, only holds so long as the laminar flow itself is, so to speak, the immediate envelope of the body. With curved surfaces, such as that of a sphere for example, a point may be reached where the main laminar flow will separate from the surface of the sphere, enclosing between its inner boundary and the surface of the sphere a mass of eddying turbulent fluid. In such case we must consider the space surrounded by the laminar flow as having the geometrical form of the inner boundary of the laminar flow itself. In a similar manner, where the body is surrounded wholly by turbulent flow, it is found that, assuming the outlying body of fluid beyond the turbulent boundary layer to be free or substantially free of turbulence, the lines of flow in this outlying fluid follow closely the paths given for the flow of an ideal fluid.

The distribution of the velocity through the thickness of the laminar flow is found, experimentally, to vary from the normal velocity of stream flow at its outer boundary, nearly by a linear law, down to a vanishing value at the surface of the body itself. In fact, it is accepted, as we know, that a layer of fluid, say one molecule thick, immediately in contact with the surface of the solid is, as it were, bound to the surface and hence at rest relative to the solid. From this zero velocity at the surface, then, the velocity in the laminar layer increases nearly by a linear law with distance, out to a zone approaching

the outer boundary of the layer, whence more gradually it acquires the normal stream velocity.

This entire body of phenomena suggests the existence of a shearing resistance operating between two layers or sheets of the fluid, or ultimately between two molecules of the fluid, moving near each other in parallel lines and at different velocities. In fact the Navier-Stokes equations for viscous flow which are formed from the classical equations of flow for an ideal fluid, by the addition of terms representing such a shear, give, as we know, a very satisfactory account of laminar flow for such simple cases as admit of a solution of the resulting equations. Unfortunately it is only the simplest cases such as flow through a straight pipe, along a plane surface, or about a sphere or ellipsoid, which admit of satisfactory treatment by means of these basic equations.

The characteristics of laminar flow of special practical interest are:

(1) The thickness of the layer as it increases from nothing at the first point of contact to its maximum or ultimate thickness;
(2) The thickness of the layer as dependent on velocity;
(3) The gradient of the velocity from the surface of the solid boundary outward into the body of moving fluid;
(4) The resultant drag on a unit of the surface of the body at any point along the flow;
(5) The resultant mean drag per unit of area for the body as a whole. Obviously (5) will follow from (4).

With a knowledge of the physical characteristics of the fluid and application of the principle of the transfer of momentum, these all follow from the solution of the Navier-Stokes equations, where such solution is feasible, as with certain simple cases well known in the literature of the subject. Where the direct solution is not feasible, solutions may be found in various cases by the use of simplifying assumptions. Thus guided by certain properties of the Navier-Stokes equations, and with reasonable simplifying assumptions, Prandtl and others have extended the treatment to a considerable number of practical cases. By such means and with numerical coefficients checked by experience, solutions are found which

agree well with observation, including the law of increase of the thickness of the layer with distance from the leading point of the solid and with the velocity of stream flow, the relation of the local friction per unit area to the various conditions of the flow and the relation of both the mean and the local coefficients of friction to the Reynolds number.

The items of special interest in connection with laminar flow back of the phenomena themselves, relate to the source of the shearing resistance which appears to operate between the successive layers of fluid in a laminar flow complex; and likewise of the force which binds a layer of the fluid, at least one molecule thick, fast to the solid boundary surface. These forces of shear and of the bond between a solid and a fluid are classified under the general term intermolecular. Our understanding of these forces, as we shall see later, is far from satisfactory, and we may indicate summarily the outstanding problems for the future, with special reference to laminar flow, under the four broad heads:

(1) Improvement in the methods of handling the Navier-Stokes equations in such manner as to extend their application to cases less simple than those which now seem to form the limit of practical use.
(2) In the absence of exact solutions, improvements in methods of approximate solution, or admitting of continued and closer approximation as desired.
(3) Extension of experimental knowledge covering the less simple cases, especially over a wide range of operative conditions, the better to check and control the simplifying assumptions on which our present formulæ depend.
(4) A better understanding of the source, character and laws of operation of the intermolecular forces to which the existence of viscous shear and intermolecular bond is attributed.

We turn next to a brief survey of the phase of turbulent flow. The turbulent layer may be formed at the first contact with the body, as in the case of a fluid already turbulent or flowing with high velocity and entering a cylindrical pipe; or, as already noted, the boundary layer flow may at first be laminar with transition to turbulent at some point along the

line of flow. Even with turbulent flow it seems necessary to assume the existence of a very thin sub-layer in which the flow is laminar with the inner layer of molecules of the fluid bound fast to the surface of the solid and hence with velocity zero relative to this surface. From this sub-layer outward, the velocity increases through the thickness of the turbulent layer, to the normal velocity of stream flow at its outer boundary. Again, the turbulent flow, after formation and flow over the forward part of a body, may separate from the surface leaving between what was the boundary layer and the surface of the body, a mass of water made up of eddies and whirls, constituting what may be termed large grained turbulence, which then streams behind the body forming the so-called turbulent wake.

With turbulent flow, due to the complexity and chaotic character of the particle paths, to our ignorance of their geometrical detail and of the immediate causes which determine this detail, it appears hopeless to look for any treatment by way of basic equations of fluid movement. However, there are certain kinematic features of turbulent flow by means of which, statistically, the velocity characteristics may be expressed. These are the mean velocity of flow which may be denoted by $\bar{u}$ and then embroidered upon that, so to speak, mean oscillatory perturbations in three coördinate directions and which may be denoted by u', v', w'. With this basic picture, as we know, there has been developed, by Prandtl, Karman, G. I. Taylor, Blasius, Dryden, Tolmien, Pohlhausen and others, a very extensive literature on the subject of turbulent flow. The mathematical approach has been by way of a study of molecular or small unitary diffusion, using statistical methods and aided by applications of dimensional theory and the principles of similitude, the whole based on certain clever and sometimes intuitive hypotheses as to such basic features of the problem as may be needed in order to make possible a start by orderly mathematical procedure. With the aid of coefficients, the values of which are drawn from experiment, it has been found possible to develop, in these ways and for relatively simple forms, a quite satisfactory account of the distribution of mean velocity through the thickness of the turbulent boundary layer and hence of the

transfers of momentum which appears as a drag or resistance to the motion, ultimately carried to the solid body by way of the layer of molecules which, as above noted, is assumed as bound to the surface of the body.

In the study of practical problems, the coefficient of friction and its relation to the conditions of the problem, as indicated by the Reynolds number, assume special importance. A first approach was made to the development of such a relation, through reasonable assumptions, leading to the one-fifth power law, as developed by Prandtl and Karman. This led to quite satisfactory results over a considerable range of values of the Reynolds number. Extension to large values of the number, however, gave inconsistent results, indicating that the basic assumptions were not valid and that no simple power law for this relation could be accepted as generally applicable.

As a different mode of approach, Karman, through the assumption that the flow patterns of the turbulent interchange in the neighborhood of different points are similar, differing only in the scales of length and time, has developed a mode of treatment for velocity distribution which resulted in a logarithmic law to which variation with the seventh or eighth root is found to furnish a close approximation over a considerable part of its range. This logarithmic law is found to agree very well with the results of experiment over a wide range of operative conditions. From this law of velocity distribution, the transfer of momentum can, of course, be found and hence the friction at a local point or the mean over an extended surface. This development has been especially satisfactory in bringing the earlier heterogeneous and discordant results on the skin friction in smooth pipes into a highly consistent and satisfactory order. Due to the difference in the law of velocity variation with distance from the boundary surface, as between laminar and turbulent flow, the resultant exchange of momentum and the consequent drag or resistance to relative motion is much greater for turbulent than for laminar flow. There results the practical desideratum of maintaining laminar flow wherever possible, or over as large a part of the surface of the solid as possible.

Apparently the most promising present line of advance in the study of the immediate phenomena of turbulence, lies in

the direction of the statistical approach, involving the development of a series of velocity correlation functions as a measure of what may be called the "structure" of turbulence. Karman, G. I. Taylor and others have already made marked advance along these lines.

The picture of turbulent flow which has led to these successful attacks on certain practical phases of the problem is primarily one of the diffusion of molecules or of small unities of the fluid from the layers adjacent to or near the body, out into the main flowing stream with carriage of momentum, thus giving the effect of a drag or resistance against the relative motion of the fluid and the solid. It may be noted here that it is the type of molecular diffusion characteristic of turbulence in air which is the effective agent in the diffusion of heat or of dust, smoke, a foreign gas, odors, or anything like, which is air borne. Similarly in liquids, the same type of chaotic movement, either of molecules or of small unitary elements of the liquid, is effective in securing the diffusion of heat, of coloring matter, of any foreign substance in solution or of fine particles in suspension. It is this characteristic which makes possible the carriage of enormous quantities of silt by rapid flowing streams. The relatively heavy particles of silt are continuously settling to the bottom and as continuously are picked up and carried along, rising and falling in somewhat chaotic fashion throughout the body of the stream.

A very important factor in the problem of turbulent flow is presented by the condition of the surface of the solid body as regards roughness or smoothness. Some progress has been made in evaluating this characteristic of the surface in its effect on the conditions of flow otherwise, and in framing a measure of roughness in dynamic terms.

The principal features of turbulent flow of practical importance are the following.

(1) The thickness of the turbulent layer as affected by the various circumstances of the flow;
(2) The law of mean velocity variation with distance from the bounding surface;
(3) The law of velocity fluctuation, both along and transverse to the direction of flow, affecting, as this does, the rate of molecular diffusion and of momentum exchange;

(4) The conditions of the flow which determine the onset of turbulence or the transition from laminar to turbulent flow;
(5) The conditions which determine the separation of the flow as a whole from the surface of the solid, as noted above;
(6) The resulting drag on the motion between the solid and the fluid at any specified point on the surface of the former, and the mean value for the body as a whole.

As noted above, good progress has been made in what may be termed tentative or empirical theories relating to these various features. In none of them is the theory what can be called fundamental and in none of them are the results entirely general or wholly satisfactory.

Now what are the actual physical conditions, the basic parameters as we may term them, which appear to be available as the determining and controlling factors in these phenomena? Neglecting gravity which may usually be considered uniform throughout the domain of the flow, we have first, the characteristics of the body—size, form, character of surface, and attitude relative to the direction of flow; and second, the characteristic of the fluid—density, viscosity, and pre-turbulent state; and finally, the relative velocity between the fluid and the solid. With regard to air, one of the most important of the fluids with which we have to deal practically, there is a further characteristic which does not appear, as yet, to have been taken into account as an influential factor in determining the character of the movement of a fluid relative to a solid; and that is, the electrical state of the air as measured by its degree of ionization. It would appear that this characteristic should be added to those noted above, at least for the case of the relative movement of air and solid bodies. We known that this characteristic of the air plays an important, even a controlling part, in atmospheric phenomena such as the formation of clouds, fog and rain drops. It seems, then, reasonable that it may play a role of some significance in the phenomena of the movement of air relative to a solid body, and especially as a factor in determining the conditions of the transition from laminar to turbulent flow. The significance of ionization as a factor in the relative movement of fluids and

solids would doubtless hold generally for all gases and conceivably also for liquids. It does not seem likely, however, except in the case of air, that the influence of this factor would be of any serious practical importance.

We may now consider briefly the various items of the turbulent phase, (1) to (5) above, relative to the parameters available, with note of the directions in which extension of our knowledge or improvement in our methods seems especially needful.

First with regard to these various characteristics of turbulent flow, we may safely say that they depend on all of the basic conditions of the flow as noted above. The manner in which these basic parameters enter into relation with the various characteristics of turbulent flow forms, of course, the substance of the developments referred to earlier, and as set forth in the present rather extensive literature of the subject. Mention should be made, however, of the "Reynolds Number," mentioned above in connection with laminar flow; a derivative non-dimensional parameter introduced by Osborne Reynolds in his epoch-making pioneer work in the domain of fluid mechanics. This parameter, representing, as we know, some significant dimension of the body, relative velocity, density and coefficient of viscosity of the fluid, has furnished an almost universally significant combination of these four basic characteristics of the flow with reference to the widest variety of flow phenomena.

Another non-dimensional parameter introduced by Prandtl and involving shear, density, distance from the surface of the solid and the coefficient of viscosity, has also been of great value in connection with the discussion of the problems of turbulent flow.

Mention may also be made of the introduction by Prandtl of a length-parameter of the turbulent friction-mechanism to which he has given the name "mixing length" and of Karman's "universal constant" k defined by the equation:

$$l = k(du/dy)/(d^2u/dy^2),$$

where u is mean velocity, y is distance from the solid surface, and l is the characteristic length of the flow pattern. Other direct physical or geometrical conditions which play important

parts are such items as, the degree of curvature of the bounding surface of the solid; the fairness or continuity of such curvature; the degree of roughness of the surface; the attitude of the body relative to the direction of the flow, and the preturbulent condition of the fluid. It is known by observation that large Reynolds number, high curvature of the surface, abrupt changes in the direction of the surface, marked roughness or irregularity of the surface and turbulence in the fluid when it first reaches the vicinity of the body, all contribute to a shift upstream of the zone of transition from laminar to turbulent flow, or to an early onset of turbulence in the entire flow and to a greater degree of turbulence as a whole.

An attitude of the body resulting in a marked asymetry of the flow on the two sides (as with a plane set oblique to the flow or the wing of an airplane with increasing angle of incidence) is likewise conducive to increased turbulence in the flow.

The transition from laminar to turbulent flow and its controlling conditions has been in recent times and is still the subject of special study in the aerodynamic laboratories of the world. These studies recently have been directed especially to the conditions which determine the location of the zone of transition on a body such as the wing of an airplane. In the case of such a body, the flow around the nose and for a distance back, will be laminar. Then abruptly the laminar flow breaks down and transforms into turbulent flow with distinctly less favorable results on the skin friction of the wing surface. It is obvious that if this transition could be pushed farther back toward the following edge of the wing, thus placing an increasing part of the surface under the influence of the air in laminar flow, the result would be a distinct decrease in wing drag with resulting gain otherwise.

The problem then is, what are the conditions which determine this transition, and what measures, if any, can be taken to place this zone of transition farther toward the following edge of the wing? An entirely similar problem presents itself in connection with ship propulsion and, more broadly, in any case where the viscous drag between a fluid and the surface of a rigid body becomes of economic importance.

Recent studies [1] have served to set forth many of the conditions which determine this transition and to suggest certain of these conditions as favoring continuance of the laminar flow. These studies thus far are admittedly incomplete and indicate that the inventory of influential causes of the transition is not yet exhaustive. An examination of this point by Jones by way of an attempt to relate the location of the zone of transition on a given wing to a series of parameters involving the more obvious basic conditions, seems to indicate that there are still other influential factors which yet remain to be identified.

Thus Jones suggests that the conditions which determine this abrupt change in the character of the flow may include something in the previous history of the flow. It is pointed out that the observations on which this analysis is based are time means of conditions which are really fluctuating. Dryden [2] has shown that such fluctuations in the location of the zone of transition do exist and that the period of this movement is surprisingly long. The immediate cause of these fluctuations has yet to be identified and its influence on the mean location of the zone of transition determined.

There is the further basic characteristic, already noted, of ionization in relation to the movement of air. It would appear not unlikely that this characteristic might play some part in determining the conditions of flow along and near a body such as the wing of an airplane.

This general question of the influence of the degree of ionization of the air, not only with regard to the location of the transition from laminar to turbulent flow, but also in connection with the phenomena of fluid movement more generally, would appear to constitute a phase of the study of the foundations of fluid mechanics meriting careful investigation.

Regarding the separation of the flow as a whole from the surface of the body, the more immediate cause has been shown to be the development of an inverse pressure gradient forcing, as it were, a flow counter to the main turbulent flow near the solid surface, and forcing this main flow away from the solid boundary. The form and attitude of the body, together with

[1] See Jones, B. Melvil, *Journal of the Aeronautical Sciences*, Jan. 1938.

[2] U. S. National Advisory Committee for Aeronautics Report No. 562, 1936.

the Reynolds number and the degree of pre-turbulence, appear to be the chief factors in determining this phenomenon. It is this condition which causes the abrupt change in the drag of a sphere as in the well known experiments of Eiffel and Prandtl. Before separation the flow follows well around the surface of the sphere with only a small wake comprising eddies and large grained turbulence. With separation a little before the 90° point, the wake becomes very much larger with decrease in effective pressure on the after surface and increased over all resistance to the motion. Various other factors doubtless affect and aid in the determination of this phenomenon of separation. The entire subject is of high practical importance and merits further study.

It follows from this brief picture of the present status of our knowledge of viscosity and its effects on fluid motion, that such knowledge is largely empirical. Phenomena are observed, tentative hypotheses (sometimes intuitive) are adopted, developed by clever applications of mathematical methods and checked back by observations and experience. Indeed, with the complexity of the problem the first approaches could scarcely have been otherwise. Such methods and the results derived therefrom lack, of course, generality of application. Thus there is need for a more general theory regarding the distribution of the mean velocity $\bar{u}$ and likewise of the character and distribution of the velocity fluctuations, u', v', w'. In many cases, moreover, it is by no means sure that all of the influential factors or conditions have been included in the development. Thus with reference to the influence of roughness on these phenomena, progress has been made with a good approach to a dynamical measure of roughness as related to a parameter representing what may be termed the "size of the grain" of roughness. But this is hardly enough; there is need for the introduction of another parameter representing what may be termed the frequency of the grain. There is also need for some approach to a rational treatment of bumps, waves and irregularities of larger magnitude than those which seem properly to fall under the term "roughness."

It is known from observation that below a certain Reynolds number, roughness has but slight if any measurable effect on

the coefficient of friction. The low Reynolds number means a relatively thick laminar sub-boundary layer, completely submerging the elements of roughness, and thus shielding them from any direct influence on the turbulent part of the flow. With increase in the velocity and in the Reynolds number, the thickness of the sub-layer becomes less, they emerge and take part in the conditions affecting the turbulent flow, with increase in the friction, all as indicated by experiment.

These conditions introduce a difficulty in the treatment of friction with roughness. Even with constant velocity, the thickness of the sub-layer will vary along the line of flow contact, with resulting variation in the influence of the roughness even though the roughness itself be uniform in character over the entire surface in contact with the fluid. A comprehensive treatment of these conditions would, therefore, require a knowledge or estimate of the thickness of this sub-layer along the line of flow, with the varying degree of emergence of the grains of roughness and the resultant variation in their effect on the turbulent flow. This will involve, obviously, a very complicated and difficult procedure, to which, however, in the future, some effective approach may well be made.

There is need for some more general treatment of the influence of attitude and form in general on these various phenomena. In the case of tubular or channel flow, there is need of further study on the effects of convergence or divergence as well as curvature in the line of flow along the channel. There is need for further study of pre-turbulence as to its essential characteristics and determining parameters. Among other items, there is need for some method of specifying the degree of pre-turbulence by something of the nature of a characteristic linear dimension. A serious difficulty in the treatment of pre-turbulence or, as it might be termed, diffused or general turbulence, is the fact that this condition may involve vortex and eddy motion, large scale and small, and not steady as to size or character. These conditions render more difficult the application of statistical or other methods which may be applied with some measure of success in the case of what may be called boundary layer turbulence. There is need for more definite knowledge of the influence of pre-turbulence on the transition from the laminar to the turbulent phase, and

likewise on the phenomena of separation. And again, as noted above, in the case of air, there is need for an examination as to the influence of ionization as a possible factor in these various phenomena, and especially as affecting diffusion rates and the transition from laminar to turbulent flow. There is also need for further study of the effects of what may be called large scale turbulence as compared with the small scale turbulence such as that more definitely characteristic of conditions in the boundary layer in the case of bodies with smooth or moderately rough surfaces. There is need of further study of what may be termed the birth of turbulence, considered as resulting from a breaking down of the conditions which determine laminar flow; and likewise of its decay and final transformation into molecular agitation, manifested as heat and with a resultant rise in the temperatures of the system. More fundamentally, there is need, if possible, to get back of these phenomena to the more immediate determining causes in the fluid. There is need of a more adequate picture of the constitution of a turbulent fluid and of the laws of what we have termed diffusion, carrying with it, as it does, a transfer of momentum with the result of a drag or resistance to the relative motion.

Very interesting problems arise in the case of the motion of a fluid relative to a fluid boundary—such as the air in a wind blowing over a surface of water, the slip stream of a propeller either in air or in water, or ocean currents such as the Gulf Stream. Limitation of space prevents more than the briefest reference to these cases. The same general methods have been used as for the case of movement relative to solid boundaries. Both laminar and turbulent flow are recognized. The interesting result develops that for certain assumed conditions the turbulent friction varies as the square of the speed, with constant coefficient (independent of Reynolds number). It is also relatively high, corresponding to the conditions with a very high degree of roughness for flow over a solid.

There is need here for a more comprehensive theory, especially as covering the relative diffusion laws as affected by combinations of—differences in character (air and water), differences in temperature, and the presence of foreign matter in suspension.

Throughout the entire range of the phenomena of the relative motion of a fluid and a solid body, or of two fluids of different character, or of a stream of fluid within a body of fluid of the same character but under different physical conditions, we come ultimately, so far as the fluid is concerned, to the one controlling and determining characteristic, viscosity. What, then, is the nature of this viscous drag which appears so plainly as an adequate cause in the phase of laminar flow, and to which, less directly in the case of turbulent flow, we must trace the existence of a transfer of momentum as between the fluid and the body, with the result of the creation of a drag or resistance to the relative motion between the two? This in the end comes down to the question of the nature of the physical forces between adjacent molecules in a fluid.

Writers on fluid mechanics have, as a rule, been content to accept the existence of such forces without special inquiry as to their source or character. Broadly they are referred to as intermolecular forces. Before considering the presumptive background of such forces, let us recall briefly their external manifestation, especially in relation to the degree of molecular kinetic energy, characterized, as it is, by what we call temperature.

In solids, a bar of copper or a piece of ice, for example, below some critical temperature varying with the substance, the configuration of the molecules remains fixed within very narrow limits. The molecules, with a certain mean intermolecular distance, resist further separation, closer approach, or sliding movement one relative to the other. They resist extension, compression, or shear. It is these forces, then, taken in conjunction with the particular temperature of the body, to which is due the maintenance of the solid state. In these same bodies, however, with the temperature raised above the critical point (temperature of melting) the forces resisting shear and extension become greatly reduced, though they are by no means negligible, while the forces resisting compression undergo but slight change. In other words, liquids show small but sensible resistance to shear and to tension, with high resistance to compression. If we increase still further the level of the molecular kinetic energy and carry the temperature above a second critical level, the substance

takes on entirely new physical properties. A level of molecular kinetic energy is finally reached where the molecules attain and maintain a mean range of molecular separation over which the intermolecular forces, which were paramount in the solid and liquid states, have now become seemingly negligible. Or if we should assume them still to act in some infinitesimal degree, such influence is small and apparently negligible in comparison with the reactions which result from the so-called collision contacts of the free-moving molecules. In any event the generally satisfactory account of the physical properties of matter in the gaseous state which is furnished by the hypothesis of an assemblage of free flying molecules with elastic collisions, indicates that forces resulting from such collisions have now become paramount. When we inquire into the nature of these molecular collisions, however, we are brought immediately back to the domain of intermolecular forces. Here, however, the range of approach is beyond that for which forces of attraction become controlling. The resultant reaction is one of repulsion, against which the kinetic energy of the molecule is able to force approach only up to a certain point, followed by rebound and separation in the manner characteristic of what we term elastic collision. In the state of gas, then, there is no resistance to increase of molecular separation. On the contrary, except as restrained by boundaries or a controlling force such as gravitation, the constant drive is toward greater and greater separation. Resistance to compression we refer to collision forces, but these are, as we have seen, only molecular forces in the outer range of repulsive action. For forces in opposition to the sliding motion of one molecule relative to another, analogous to shear in solids and viscosity in liquids, we seem to find no adequate source in the forces which are invoked for solids and liquids. There is every reason to believe that the sliding movement of one molecule of a gas relative to another would be attended by some manifestation of inter-molecular force. But the typical encounter of gas molecules is assumed rather to be of the collision type and in any case they do not appear to approach within the zone of the action of attractive forces. We are left, therefore, in the case of gases, simple with repulsive forces as the result of molecular encounters. Never-

theless it is sure that in gases there is something analagous to viscosity in liquids and to which we naturally give the same name. It seems obvious, however, that we must seek the source of this characteristic of gases in a different category of molecular relation from that which has appeared adequate for solids and liquids.

So much for the external manifestations of these intermolecular forces. If, however, we are to make progress on a broader base, we must know something more regarding these forces themselves—something of their background and of the laws of their action.

This, then, represents one of the outstanding problems for the future. A good deal has been learned, especially during the years of the present century, regarding the way in which these forces act, and the laws of the propagation of these effects through the fluid. This has been accomplished by clever combinations of mathematics and experimental research, the one aiding and directing the other. There is still lacking, however, an adequate generalized theory relating these forces, as to character and magnitude, to the conditions of molecular or atomic aggregation. Here we enter immediately the domain of physical chemistry or of atomic and molecular physics, according as we may prefer one term or the other.

Any discussion in detail of this broad subject is quite foreign to the purposes of the present paper. We who are concerned with the laws of fluid mechanics and with the phenomena which these laws seek to correlate, must look to the specialists in atomic and molecular physics for the ground work of a better understanding of viscosity and related phenomena. It may, however, be of interest to endeavor to gain some long range view of this field and of the character of the molecular interactions to which we may look as the immediate source of these force manifestations with which we are concerned.

If, then, we are to seek the source of these forces, it must obviously be within the atom itself. The years of the present century have given us an almost bewildering array of theories of the constitution of the atom, with an ever increasing assemblage of subatomic units as building blocks. And again

we have learned to view at least certain of these units, sometimes as particles and sometimes as waves. But whether we focus on the wave aspects or the particle aspects, agreement is general that certain of these units are endowed with electric charges, either positive or negative (proton, electron, positron, X particle), while some are neutral (neutron and neutrino?). For the limited scope of our present purpose, it will be sufficient to note simply the electric character of at least a part of these sub-atomic units and to assume the existence of fields of force resulting therefrom, and which must extend beyond the boundaries of the atomic or molecular volume itself. The word "boundary" is used, of course, only in the sense of a geometrical abstraction. We can hardly conceive of a field of force coming to zero just at the boundary nor can we imagine, at the boundary, an abrupt discontinuity with drop to zero. Again we must remember that the outer electrons are assumed to be engaged in some type of orbital motion. This introduces cyclical changes in the components of this field with complex phase relations. Again, with electron spin, magnetic fields are added to the complexity of the situation. Again by the mutual action of two such complexes—two atoms or two molecules—induction effects will result with consequent modification of the field configurations of the interacting atoms or molecules. The trouble, indeed, is not with any lack of external fields of force, but rather with their overabundance and complexity. Thus Hildebrand [3] lists the following five types of potential which, at least, must be considered in an approach to the problem of inter-molecular forces:

(1) Potential between charged ions.
(2) Potential between permanent electric dipoles.
(3) Potential between a permanent dipole and the temporary dipole it may induce in another molecule.
(4) Potential of actual chemical or electron pair bonds that may be formed.
(5) Potential due to the interactions always occurring between electron systems, independent of those noted above.

It appears natural that, in many or perhaps most cases, the resultant field for an isolated molecule should show some

[3] *Journal Faraday Society*, Jan. 1937, p. 144.

degree of polarity; and as we know, this is the case, giving the familiar dipole of the modern physical chemist. And again, by mutual action, we may have induced dipoles, as noted in No. 3 of Hildebrand's catalogue above, and indeed induced quadrupoles and multipoles of higher orders.

Now with this wealth of reactive material, what is known regarding the nature of these intermolecular forces and the law of their variation with distance? The familiar law of like to like giving repulsion and like to unlike attraction, with variation as the inverse square of the distance, which we accept and use unhesitatingly for distances large compared with molecular dimensions, here breaks down completely. In the older theory of the atom, how could n protons and approximately half that number of electrons bind themselves into an atomic nucleus in any way consistent with these laws? Or if we take the more modern view, how, under the same laws, can an equal or nearly equal number of protons and neutrons bind themselves into a coherent atomic nucleus? Or again, and with more direct application to our present discussion, how can an assemblage of dipoles or multipoles, at intermolecular distances, show a definite residual force of attraction? Something is needed beyond the simplicity of the older law valid for molar dimensions.

Here again there is no lack of proposed formulations of such laws. In fact the years of the present century have witnessed the development of an extensive literature on the subject of these intermolecular forces. But no formulation yet seems to be wholly acceptable. A given formulation can be made to agree with experimental observations for certain specific cases under specified and perhaps narrow conditions; but a formulation generally and broadly applicable seems still to lie in the future.

Thus certain assumptions applied with suitable quantum treatment of the disposable elements of the problem, indicate for certain ranges of intermolecular distances, interaction energies varying as the inverse 6th power of the distance and of a sign indicating resultant attraction. With the addition of effects due to quadrupoles and multipoles of higher orders, similar energies varying as R^{-8}, R^{-10}, etc. are indicated.[4]

[4] See F. London, *Journal Faraday Society*, Jan. 1937, p. 8.

At some degree of mean molecular separation, wherein the temperature enters as the controlling factor, these forces of attraction are in balance with the forces of repulsion due to the atomic nuclei. With greater separation, the forces of attraction become paramount, giving the resultant force of cohesion in solids, with tension and viscosity in liquids. For decreased separation, the forces of repulsion become paramount, with the resulting resistance to compression in both solids and liquids.

Exponential forms for the law of variation of potential with intermolecular separation have also been used with good effect. Thus quantum mechanics indicates such a form of relation for the forces of repulsion, and even the simplest form of expression for a general law of variation with distance might comprise at least an exponential term with two or more terms for the attractive forces, varying as R^{-6}, R^{-8}, etc.

Again Ward [5] finds good experimental justification for an exponential form of law for the relation of the shear force (viscosity) in liquids to the intermolecular distance. Various writers have given a wide variety of form to this type of law, which now seems well established, at least as a serviceable form for the investigation of a considerable variety of fluid phenomena.

And again, Huddleston [6] finds good evidence for an exponential form of law giving zero force (equilibrium) for the neutral mean intermolecular distance, with attraction when the distance is greater and repulsion when it is less.

We may conclude, then, with special reference to the viscosity of liquids, that modern quantum treatment of the sub-atomic units, with their assumed characteristics, is able to indicate, for certain ranges of molecular separation, residual intermolecular forces of the order of attraction, and which may, therefore, be invoked as the immediate source of tension in liquids and of the resistance to liquid shear—otherwise viscous drag.

It can, however, hardly be said that these are more than provisional theories—a limitation which necessarily prevails in large degree throughout the entire domain of sub-atomic and

[5] *Journal Faraday Society*, Jan. 1937, p. 89.
[6] *Journal Faraday Society*, Jan. 1937, p. 97.

intermolecular physics. The development of any generalized form of theory which, for intermolecular forces, would have the range and accuracy of application which the Newtonian theory of gravitation has for astronomy, is apparently quite beyond the reach of our present methods of analytical approach. When we remember, moreover, the number and complexity of the elements involved in the present problem, and recall the difficulties which even the three body problem with the simple inverse square law presents in the domain of celestial mechanics, it hardly seems within the limits of reason to hope for any complete mathematical solution, at least without the help of some new and vastly more powerful mathematical discipline than any yet available.

When we turn from liquids to gases, we find ourselves, as previously noted, confronted with a different type of problem. The significant difference, as between these two forms of matter, is found in the inverse direction in which the coefficient of viscosity changes in its relation to change of temperature. It is a fact of observation, as we know, that for liquids the coefficient of viscosity decreases with elevation of temperature, while for gases, the coefficient increases. The decrease, in the case of liquids, is to be expected with the increase in molecular energy and the resultant increased capacity of the molecule to move independently of the intermolecular forces; or as we may say, to cut itself free from their control. On the other hand, with a gas, the intermolecular forces are no longer controlling except as they determine the conditions of the so-called elastic collisions. The increase of the coefficient of viscosity with increase of temperature seems to point to the increased energy of the molecule itself as the source of this increase. Or more broadly, the nature of what we call viscosity in a gas seems to be tied in with the kinetic energy of molecular agitation. With this picture, we find, apparently, an adequate source for gaseous viscosity in the transfer of momentum between streams of molecules moving with different velocities of translation. Between the surface of a solid body past which a gas is streaming and the outer body of such moving medium, there is, as we have seen, a continuous gradation of velocity ranging from zero at the surface to the normal velocity of flow at a distance away from the body measured

by the boundary layer thickness. Within this layer we shall have elastic collisions with continuously increasing velocities of translation from the surface outward and with a consequent interchange of momentum between these molecules in such manner as to simulate a drag between adjacent moving streams or adjacent moving particles, and communicated finally to the bound layer as a viscous drag on the surface of the body itself.

While, apparently, then, the viscosity of a gas finds its immediate source in a different phase of molecular activity from that to which we attribute the viscosity of a liquid, they both trace ultimately to the same background of intermolecular forces. It is these, as we have seen, which determine the conditions and consequences of the elastic collisions and it is these likewise which hold bound to the surface of the solid body the layer of molecules which forms what may be called the foundation of the boundary layer. The same condition holds, of course, for the case of a liquid. The existence of a bound layer of molecules at a surface of separation between a solid and a fluid (either liquid or gas) is accepted as a commonplace in modern physics and for the source of this bond we must again go back to the domain of intermolecular forces.

The entire domain of fluid viscosity rests, therefore, on the action of intermolecular forces, though, as we have seen, the more immediate source may appear to be quite different as between matter in the liquid and matter in the gaseous state.

Also and more broadly, as appears from the preceding rapidly drawn picture, we may say that the entire gamut of the mechanical properties of matter must be referred to the play of interactomic or intermolecular forces on the one hand and to the kinetic energy of molecular agitation (as evidenced by temperature) on the other, and to the mutual influence which these two types of action exert, the one on the other.

Extension of our knowledge of this domain represents, then, one of the great outstanding problems in the solution of which the student of fluid mechanics has a vital interest. The problem lies primarily in the domain of atomic and molecular physics and it is to those who are expert in this field that we must look primarily for advance along the line of a more complete understanding of the phenomena of fluid vis-

cosity and of the controlling influence which it exercises in so many of the problems of fluid mechanics.

The excessive difficulty of attempting to formulate any generalized theory for the maze of interacting sub-atomic units with which such theory must deal, has been already noted. And the existence of these conditions suggests the conclusion that, until some, at the present time, unimaginable mathematical discipline is available, the advance in the better understanding of these intermolecular forces and of their mode of action, must come primarily from laboratory research with the results synthesized into some form of law of limited application, by the aid of such mathematical means as are now available. In this way, it may be found possible to develop reasonably general laws for specific substances, such as water and air, the two media for which such better understanding, from the viewpoint of practical importance, is most needed.

COMPRESSIBILITY.

Thus far, consideration has been given only to the effects of viscosity as a factor in the phenomena attendant on the relative motion of a solid and a fluid. Only brief consideration will be given to the effects of compressibility, the other characteristic specially differentiating actual fluids and the classical ideal fluid. The conditions of relative motion between a solid and a fluid which determine the phenomena of compressibility are relatively simple, compared with the corresponding case for viscosity, the literature is less abundant and apparently, once the limit passed, beyond which these phenomena appear, there is little that can be done about it. Furthermore, for liquids, the compressibility is so small as to admit of neglect in all ordinary problems involving relative motion with solids. With gases the compressibility is large, but in only a small proportion of the cases of motion relative to solids are the conditions such as to involve compressibility effects in significant degree.

As is known, the border line, or border zone, perhaps we should say, beyond which compressibility effects become of importance, is determined by a relative velocity of motion between solid and fluid approaching or equal to that of the propagation of sound in the fluid. For projectiles in flight,

for certain phases of modern high speed air transport and here and there in the operations of industry, these effects become of importance; but, on the whole, the phenomena of compressibility in our industrial and economic life are of less importance than are those of viscosity.

As to the phenomena themselves, it is known that, in the case of a projectile, for example, moving through the air with a velocity greater than that of sound, there is a thin shock wave spreading from the nose of the projectile in the form of a cone, moving forward, of course, with the velocity of the projectile, and with the angle of the cone such that the velocity of propagation normal to the shell of the cone is that of sound in air. More generally, for velocities greater than that of sound in the fluid, an abrupt change in the direction of relative flow will give rise to shock waves of this character, and the chief problems which arise in connection with the influence of compressibility, center around these shock waves, their dimensions, structure, and influence on the force reactions between the solid and the fluid.

The mathematical approach to the problems of compressibility has been by way of suitable extensions of classical theory, whereby, for a considerable number of cases, a quite satisfactory approach to practical treatment may be realized. In all such cases, however, numerical values must be checked by resort to experiment, and mathematical analysis and experiment must go forward continuously hand in hand, the same as for the treatment of the effects of viscosity.

The chief practical result of the formation of these shock waves lies in the greatly augmented resistance to the relative motion which is thereby incurred, and which finds its chief import in the domains of exterior ballistics and aeronautics.

Looking toward a better understanding of these phenomena, the problems of chief importance center about the law of formation of these shock waves in the cases of bodies of somewhat irregular form, or with bodies of generally regular form with here and there discontinuities, such as projecting rivet heads on an airplane wing. Then supplementing a better understanding of the formation of such waves, we need some better approach to a generalized theory of the energy which must be continuously supplied to maintain them, and the draft

of which from a projectile in flight, for example, gives rise to the augmentation of resistance referred to above.

In particular, there is need for a more generalized knowledge of the relation of these phenomena, and especially of the added drag, to the velocity of relative motion in relation to the velocity of sound in the medium. Thus the effects of compressibility begin to appear in measureable degree at velocities of the order of 70 per cent. or 80 per cent. of that of sound, increasing as the velocity is increased, and with an abrupt further increase at and beyond this velocity. While we can do little or nothing to avoid these conditions once the velocity approaches or passes beyond the critical value, it is of importance that we should be able to give to the body such form as will involve the minimum of shock wave energy at the proposed velocity; and further, that we should be able to form in advance some reasonable approach to the measure of such energy; or in other words a measure of the drag on the body resulting therefrom, and hence of the price which must be paid for speeds approaching closely to or exceeding the velocity of sound in the medium.

With some extension of our present methods of mathematical analysis combined with the results of adequate experimental research along these lines, the situation with regard to what may be called "applied theory" in this domain, would be in a fairly satisfactory condition.

The most active present interest in this phase of fluid mechanics is found in applications to the problems of aeronautics, where already commercial speeds at high altitudes require recognition of compression effects. An extension of wing theory to include such effects has already been put into promising form by the work of Prandtl, Schlichting, Kármán and Budemann.[7] There is likely to be a continuing and live interest in these problems, and we may look with confidence for further refinements in this extended wing theory, at least to the point of satisfying the requirements of practical design for airplanes in stratosphere flight.

Compressibility effects are also in evidence in the case of the flow of a gas along a closed conduit or escaping in the form of a jet. Examples of such conditions are found in industry,

[7] Atti del Convegno Volta, Rome, 1935.

as in the nozzles of a steam turbine, escape of gas under high pressure through nozzles, etc. In aeronautics an important example is found in modern high speed or supersonic speed wind tunnels. In these cases, changes of volume in the gas due to varying cross section of the channel with varying velocity of flow are superimposed on the conditions affecting the formation of shock waves, and the conditions of the problem generally are more complex than in the case of a solid body moving through an indefinitely extended gaseous medium. Shock waves are not always formed, even though the velocities may exceed that of sound. The latter now, however, is a variable quantity since it will depend on the local density of the medium, which may vary from point to point along the line of flow. There has been a considerable mathematical development of these conditions and the simpler cases may be dealt with in a fairly satisfactory manner.

There is need, however, for a better understanding of the more complex cases, where there may be changes, gradual or abrupt in the direction of the flow or when the changes in cross section may be abrupt. In particular there is need for some more general criteria for the formation of shock waves in such cases, and for a more generalized theory of the energy relations along the line of flow.

In this paper, only partial views of the broad domain of fluid mechanics have, of course, been given. The particular purpose has been to indicate what seem to be some of the more important lines of advance along which progress seems both needful and hopeful. As with many of our dealings with Nature, advance must here be conditioned on a wise combination of mathematical analysis and experimental research, the one checked and guided by the other. And in closing, it is safe to predict that no matter how far the future may carry the advance, there will always remain an enlarging domain of the unknown, standing always as a challenge and a stimulus to those whose work may lie in this field of fluid mechanics.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

METHOD FOR SEALING PLATINUM TO PYREX GLASS.

A satisfactory seal between platinum and Pyrex glass, for use in the construction of chemical and other scientific apparatus, has been developed by Edward Wichers and C. P. Saylor of the Bureau's Chemistry Division.

The general problem of joining metals and glasses has been studied by many investigators, but the fact that the thermal expansions of platinum and glass are so different has always caused trouble. Thus, when a platinum wire or rod is coated with hot glass, subsequent cooling will crack the glass or pull it loose from the metal. Wichers and Saylor have surmounted this difficulty by using a seamless tube of platinum instead of a wire or rod. If the walls of the tube are thin as compared with its length (say a ratio of 1 to 12), the shrinkage forces are not great enough to crack the glass internally or to pull the metal away from it. In the case of a platinum tube within a glass tube, the relative dimensions of the glass enclosing wall also affect the tension of the boundary. The lower limit for the ratio of diameter to wall-thickness of the glass for this type of seal is set by the resistance of the glass to failure by cracking of the entire wall.

In addition to direct testing for vacuum-tightness, seals made at the Bureau have been examined microscopically to find whether any strains existed, to discover internal cracking, and to locate possible separations of the metal from the glass. The mechanical principles governing the platinum-pyrex seals can also be applied to other metal-glass seals of the tubular type. From a knowledge of the mechanical and thermal properties of particular glasses and metals, the dimensions of parts of the two materials which are likely to yield satisfactory seals can be calculated. If the cross-section of a thin-walled metal tube is insufficient to accomplish a desired purpose, such as the introduction of a given electrical

* Communicated by the Director.

current into an apparatus, a rod with a short tubular jacket welded to it can be used.

The new type of seal is simple to construct, and therefore does not require any unusual apparatus or extraordinary skill in glass-blowing.

IMPROVED RADIUM DETECTOR.

Situations frequently arise in which it is desirable to determine the extent of accidental contamination by radioactive materials. Such contamination occurs in research laboratories where radioactive studies are in progress, and also in commercial plants where radioactive materials are handled. An important example of the latter is the dial-painting plants, where self-luminous radium paint is applied.

In the *Journal of Research* for July (RP1223), L. F. Curtiss describes a portable Geiger-Muller counter operated entirely from the alternating-current mains, which permits a rapid and accurate determination of such contamination wherever it exceeds the equivalent of about one-half microgram of radium per square meter. The device is also sufficiently sensitive to determine the presence of a microgram of radium in a living person and therefore may be used for routine test of workers, their garments, and objects habitually handled by them. The instrument is very rugged, readily portable, and silent in operation. Requiring no batteries of any kind, it is always ready for use. Commercial radio parts are used throughout, with the exception of the tube itself, so that there is little danger of failures, and the parts are easily replaced if they should fail, though, as they are used well within their ratings, this is not likely to happen. The indicator is a milliammeter, which is arranged to have a very steady deflection under constant conditions, at the same time being sufficiently sensitive to measure 1 microgram of radium at a distance of 1 meter. The device may, therefore, be used for intercomparison by gamma radiation of samples of radium of low activity. It has been tested under practical conditions and has been found well suited for surveys of contaminated locations. It also is a very sensitive detector for lost radium preparations and for testing radium ores of commercial value.

STABILITY OF LEATHER.

Additional evidence of the validity of pH values for indicating the stability of leather has been secured in the course of work recently completed by R. C. Bowker and Everett L. Wallace and presented before the American Leather Chemists' Association on June 7. The pH value of leather, determined on a water extract in equilibrium with the leather, is a measure of effective acidity. Previous researches have shown that leather starts to deteriorate when its pH value is below 3, regardless of the combination of materials, and methods used in making it.

Before the significance of pH values had been demonstrated, the acidity of leather was determined by the Procter and Searle method, which consists essentially in ashing a sample of leather in the presence of an excess of alkali and titrating the excess alkali in the residue. The equivalent of the alkali used in the ignition is expressed as sulfuric acid and has been taken to represent free mineral acid in the leather. It is now recognized that such is not the case, since many sulfur-containing materials are used in the making of leather, which are erroneously determined as free mineral acid by this method. The maximum amount of acid permissible was about 1.0 per cent. Frequently leathers contain as high as 1.5 per cent. of acid as determined by this method and such leather is considered by some to be sufficiently acid to undergo deterioration.

In order to study this point several commercial leathers having different Procter and Searle values and different pH values were prepared, tested for initial strength, aged for two years, and tested again for strength. All of the leathers had pH values of 3 or higher, while the Procter and Searle values varied from 0.85 to 1.36. No serious deterioration, as measured by loss in strength on aging, occurred with any sample.

This work on commercial leathers confirms results previously obtained on experimental leathers, and demonstrates the validity of pH values and the invalidity of Procter and Searle values for indicating stability.

PHOTOGRAPHIC FILM FOR PRESERVING RECORDS.

An investigation of the suitability of photographic film for record purposes has been conducted under the direction of B. W. Scribner, as a logical extension of the Bureau's general research on the preservation of records which was started in 1929. The results of the work on film are summarized in Miscellaneous Publication M162 which has just been released.

During the past decade, photographic film has become very important for the reproduction of records, because of the great saving in storage space made possible by miniature prints, the simplicity of the reproduction process, and its low cost. Special cameras are available for automatically photographing records as fast as they can be passed before the lens, and suitable reading devices have been developed. Films are used for copying records originally printed on paper of poor quality and to minimize wear of original records, as well as to render such material more generally accessible.

The film bases are designated according to the chemical process used in their manufacture. Two types are available, one of which is coated with a photographic emulsion, while the other has a dye incorporated in the base for forming the photographic image. Films of the first type (nitrate base and acetate base), and those of the second type (viscose base and acetate base) were studied.

As in studies of the stability of paper, the deterioration of the films was accelerated by heating them at 100° C. They were then tested for change in folding endurance and in chemical characteristics. At the end of 30 days' heating, the film having an acetate base retained 67 per cent. of its folding endurance, while the viscose base retained 13 per cent. The nitrate film had no folding endurance at the end of 10 to 15 days. The same relative stability was shown by the chemical tests. From these results it is concluded that acetate film of the quality tested is suitable for permanent records, that the nitrate film is too unstable for records that are to be kept a long time, and that viscose film is in an intermediate position similar to that of papers made from a medium grade of bleached wood fibers. The images on the acetate and the viscose film did not fade appreciably under the heat treatment or when exposed to light. Values are given for the stability,

chemical purity, and strength of acetate film considered suitable for permanent records.

As the acetate film becomes brittle when dry, it is recommended that it be stored at a relative humidity of 50 per cent. The acetate film otherwise presents no particular storage problem since neither it nor the viscose film is more inflammable than paper. On the other hand, the nitrate film is very inflammable and requires special storage cabinets and vaults for the prevention of fire and explosion. A study of the area of relief vents required to prevent explosion of storage vaults for nitrate film indicates that possibly larger vents than have been recommended should be used.

In the use of films, it is suggested that damage to the images through the scratching of films or the handling of them be minimized as much as possible by frequent cleaning with carbon tetrachloride and the use of clean, white gloves in handling them.

Copies of M162 are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

TESTS OF FLASHBOARDS.

The name "flashboard" is a term invented by engineers to describe a temporary wall, usually of planks, placed on the top of a dam to store water when the stream is high for later use during the dry seasons for power, navigation, or irrigation.

As this wall is on top of the dam it is most essential that, in the case of a sudden flood, the supports holding the wall should automatically fail and allow the flood to pass over the dam. If this requirement is not fulfilled absolutely automatically, without the services of any attendant, the flood, overtopping both dam and flashboards, may prove too much for the former and may wash the entire structure into the torrent—causing tremendous loss to the owners of the dam and to the people downstream.

To store water thus at the top of the dam by increasing its height would be very costly compared to the light flashboards. This saving in cost is sufficient to justify also the use of flashboards for maintaining a constant water level on

recreational lakes. On one occasion a flashboard gate, supported by steel pipe pins, and costing $500 saved a spillway cost of $15,000.

After making some preliminary tests on flashboards in the Bureau's hydraulic laboratory, a single-panel flashboard was set up in the main flume for establishing reliable methods of design of flashboard supports. The flashboard was supported symmetrically by two steel pipes of equal size. Water, pumped into the flume, provided pressure against the face of the flashboard. As the water rose gradually and the pipes began to bend, accurate readings of the depth of water and degree of bending were made until the pipes failed and collapsed. In many of the tests the water flowed over the top of the flashboard before failure—approximating actual field conditions. Pipes from 3/4 inch to 3 inches in size were tested, and supplementary mechanical tests were also made.

By means of formulas, the bending of the pipe produced by the water pressure was converted into stress values for design. The most important feature of the tests—the stress at failure "modulus of rupture" of the pipes was thoroughly analyzed. It varied from 90,000 to 70,000 lb./in.^{2}, being smaller for the larger pipes.

The U. S. Forest Service who sponsored the investigation applied the laboratory results to the design (proper determination of size and spacing of pipe, height of flashboard, etc.) of numerous installations of flashboards for their dams. Some flashboard gates were high and narrow and some low and wide, all hinged loosely at the bottom and supported symmetrically by standard steel pipe.

For numerous floods the pipe supports failed, and these values of the headwater level agreed remarkably well with the results of the laboratory tests.

The pipes were found to bend excessively at very nearly the same value of stress, 49,000 lb./in.^{2}, and this was called the yield point of the pipe. In design, the pipes and flashboard height should be so selected that the yield point is not exceeded frequently, otherwise the pipes will be unsightly and require replacing even though they have not failed. An analysis of the results suitable for use in design of flashboard

gates will be published in the *Proceedings of the American Society of Civil Engineers*.

It is apparent that the automatic flashboard gate is fast becoming a potentiality in water conservation.

SEPARATION AND COLORIMETRIC DETERMINATION OF RHENIUM AND MOLYBDENUM.

In examining minerals or residues suspected of containing rhenium, a very sensitive test for rhenium is required because this element usually occurs in very small percentages. The yellow color produced by adding potassium thiocyanate and stannous chloride to a hydrochloric acid solution of the material to be analyzed has been used in the past as a means of determining rhenium, but molybdenum, which is often associated with it, yields a similar color. The method, as customarily applied, is therefore untrustworthy unless it has been shown that molybdenum is absent.

A method for the separation and colorimetric determination of rhenium and molybdenum, depending on differential reduction with mercury, has recently been developed at the Bureau by James I. Hoffman and G. E. F. Lundell. If a dilute hydrochloric acid solution containing both elements is shaken with mercury, potassium thiocyanate, and ethyl ether, only the molybdenum is reduced to the form which produces an ether-soluble colored compound with thiocyanate. The color of the ether extract serves for the determination of molybdenum. Addition of stannous chloride to the acid solution remaining after the molybdenum has been extracted, produces a yellow to yellowish-red ether-soluble compound which serves for the determination of rhenium. As little as 0.001 mg. of rhenium can be detected in a solution containing 10 mg. of molybdenum, and 0.01 mg. of molybdenum can be detected in the presence of 10 mg. of rhenium. Very few elements interfere, and practically all can be eliminated by a simple distillation.

The method will be published within the next few months, in the *Journal of Research* or in the Analytical Edition of "Industrial and Engineering Chemistry."

Lamp-Size Steam Generator.—(*Electrical Engineering*, Vol. 58, No. 6.) A steam generator no larger than an ordinary incandescent lamp has been developed by the lamp division of Westinghouse Electric and Manufacturing Co. Heating coils of the device are directly immersed in water, providing a thermal efficiency of 90 per cent. It can superheat steam from cold water in less than 15 seconds. The heater is made in 1,000-, 1,500-, and 2,000-watt sizes, with evaporating capacities of 5.7 lbs. of water per hour. Steam can be superheated by it to 350 deg. F. The cylindrical case of the generator is 9¼ inches long, and is made of transparent chemical resistant glass, capable of withstanding mechanical stress, internal pressure of 25 lbs. per sq. in. and instantaneous transfer from cold to boiling water or vice versa. The case is provided at one end with two heavy electrical terminals, welded or sealed directly into the glass, and another threaded pipe is sealed into the opposite end as a steam outlet. Resistance wire coiled on an insulating core occupies most of the interior, leaving space for only 5 ounces of water at a time. The steam generated by the device can be used to sterilize dishes, glassware, instruments, utensils; or for pressure cookers, chemical laboratories, small scale industrial operations. The generator can also be used to produce small supplies of distilled water for drinking, medicinal purposes, or garage use, and to provide hot water for ordinary domestic uses. It operates on an ordinary electric circuit.

R. H. O.

THE FRANKLIN INSTITUTE

MEDAL DAY AT THE FRANKLIN INSTITUTE

The annual Medal Day Meeting was held in the Hall of The Franklin Institute at three-thirty o'clock on the afternoon of Wednesday, May 17, 1939. The meeting was called to order by the President, Mr. Philip C. Staples. He stated that the awards recommended through the year by the Committee on Science and the Arts, and duly approved by the Board of Managers, would be presented at this time.

PRESENTATION OF THE CERTIFICATE OF MERIT.

Jointly to Dr. Percy Russell, Wilmington, Delaware, and Mr. E. Burke Wilford, President, Pennsylvania Aircraft Syndicate, Philadelphia, Pennsylvania. Mr. James Lee, Sponsor. The President called upon Mr. Lee.

Mr. Lee: "Mr. President, the Board of Managers of The Franklin Institute, upon recommendation of its Committee on Science and the Arts, has awarded a Certificate of Merit jointly to Dr. Percy Russell and Mr. E. Burke Wilford 'in consideration of the development and application of a simple means of regulating and controlling the speed of small electric motors.' I present them for their awards."

Mr. Staples: "Dr. Russell, Mr. Wilford, by power vested in me as President of The Franklin Institute, I have the honor to present to you this Certificate of Merit."

Dr. Russell and Mr. Wilford both expressed their appreciation.

PRESENTATION OF LONGSTRETH MEDALS.

To Arthur C. Hardy, Sc.D., Professor of Optics and Photography, Massachusetts Institute of Technology, Cambridge, Massachusetts. Mr. Lewis P. Tabor, Sponsor. Mr. Staples called upon Mr. Tabor.

Mr. Tabor: "The Board of Managers of The Franklin Institute, on recommendation of its Committee on Science and

the Arts, has voted a Longstreth Medal to Dr. Arthur C. Hardy, Massachusetts Institute of Technology, 'in consideration of the development of an accurate and reliable instrument which has greatly expedited research in the field of color, both in theory and in its commercial applications.'

"This medal was founded in 1890 in honor of Edward Longstreth, member of the Board of Managers of The Franklin Institute. Dr. Hardy."

Mr. Staples: "Dr. Hardy, in accordance with the citation just read, I am glad to present to you this Longstreth Medal."

Dr. Hardy: "Thank you."

To Jesse E. Stareck, Ph.D., Technical Director, Electrocolor Division, United Chromium, Inc., Waterbury, Connecticut. Dr. Julian W. Hill, Sponsor.

Mr. Staples: "I now call upon Dr. Hill."

Dr. Hill: "The Committee has also recommended the award of a Longstreth Medal to Dr. Jesse E. Stareck, Technical Director, Electrocolor Division, United Chromium, Inc., Waterbury, Conneticut, 'in consideration of the development of a new technique for the study of electrode phenomena encountered in the electrolysis of water solutions and the discovery of a new method applicable to the art of coloring metals.' I present Dr. Stareck."

Mr. Staples: "It gives me much pleasure to present this medal to you."

Dr. Stareck: "Thank you."

To John Strong, Ph.D., Assistant Professor in Astrophysics, California Institute of Technology, and Robley Cook Williams, Ph.D., Department of Astronomy, University of Michigan. Mr. James Stokley, Sponsor.

Mr. Staples: "The Chair recognizes Mr. James Stokley."

Mr. Stokley: "Mr. President, the Board of Managers has sanctioned the presentation of Longstreth Medals to Dr. John Strong, Assistant Professor in Astro-physics, California Institute of Technology, Pasadena, California, and Dr. Robley Cook Williams, Department of Astronomy, University of Michigan, Ann Arbor, Michigan, 'in consideration of their independent development and improvement of a process for coating astronomical mirrors with a layer of metallic aluminum

deposited thereon by evaporation in vacuo.'—Dr. Strong—Dr. Williams."

Mr. Staples: "It is interesting to note that you two gentlemen, working hundreds of miles apart, should have arrived at the same conclusion at practically the same time, for your experiments. We are delighted to recognize the merit of each in presenting these medals to you."

The two gentlemen were most appreciative of this recognition.

PRESENTATION OF WETHERILL MEDAL.

To Mr. William Albert Hyde, Director of Research, Leon J. Barrett Company, Worcester, Massachusetts. Mr. Samuel Shoemaker, Sponsor.

Mr. Staples: "Mr. Shoemaker."

Mr. Shoemaker: "Sir, I sponsor the award of the John Price Wetherill Medal, founded in 1925 by the family of that gentleman, to be awarded for discovery or invention in the physical sciences or for new and important combinations of principles or methods already known. I have the honor to present William Albert Hyde, Director of Research, Leon J. Barrett Company, Worcester, Massachusetts, for the award, 'in consideration of his discovery and development of a process for the centrifugal impregnation of objects which has materially reduced the time necessary for impregnation as compared with the prior art.'—Mr. Hyde."

Mr. Staples: "Mr. Hyde, it gives me great pleasure to present to you this Wetherill Medal."

Mr. Hyde: "Thank you. I am proud to have this award."

PRESENTATION OF HENDERSON MEDAL.

To Mr. Ralph Budd, President, Chicago, Burlington and Quincy Railroad Company, Chicago, Illinois. Dr. Rupen Eksergian, Sponsor.

Mr. Staples: "Dr. Eksergian."

Dr. Eksergian: "Mr. President, the Henderson Medal is awarded for distinguished contributions in the field of railway engineering. The Committee has selected a man outstanding in this field to receive it—Mr. Ralph Budd, President,

Chicago, Burlington and Quincy Railroad Company, Chicago, 'in consideration of his engineering ability, vision and courage in carrying out railroad construction in difficult mountainous terrain in the Northwestern part of our country, and of his other contributions in the field of railway engineering.'

"Because of unavoidable circumstances, Mr. Budd is unable to be present to receive this honor in person. He is represented by Mr. M. W. Clement, President, The Pennsylvania Railroad Company, who will transmit the medal to him."

Mr. Staples: "We are proud to bestow this award on one whose work and co-workers acclaim it well deserved. We regret with Mr. Budd his inability to be with us but thank you for accepting it for him."

Mr. Clement received the award and promised to forward it promptly.

PRESENTATION OF LEVY MEDAL.

To Kalman John de Juhasz, Associate Professor of Engineering Research, Pennsylvania State College, State College, Pennsylvania. Mr. William G. Ellis, Sponsor.

Mr. Staples: "The Chairman of the Committee on Science and the Arts presents the next candidate—Mr. Ellis."

Mr. Ellis: "As you all know, the century old JOURNAL OF THE FRANKLIN INSTITUTE is read in many lands, and has been the vehicle to carry to the world outstanding discoveries in the realm of science. In 1923 the family of Louis E. Levy, a member of our Committee, established a medal to be awarded for papers of especial merit which appeared in the JOURNAL. The paper selected this year is 'Graphical Analysis of Surges in Mechanical Springs.' It is my pleasure to present the author to you, Mr. President, to receive this award—Professor Kalman John DeJuhasz, Associate Professor of Engineering Research, Pennsylvania State College, State College, Pennsylvania."

Mr. Staples: "It is always a pleasure to meet personally the authors of the learned papers which appear in our JOURNAL and especially so when we can pay deserved recognition to them."

Professor deJuhasz: "It is an honor and a pleasure for me."

PRESENTATION OF POTTS MEDAL.

To Newcomb K. Chaney, Ph.D., Director of Research, United Gas Improvement Co., Philadelphia, Penna. Dr. Hiram S. Lukens, Sponsor.

Mr. Staples: "I now call upon Dr. Lukens."

Dr. Lukens: "The next gentleman to receive an award is a Philadelphian, although not by birth. His name is well known in the field of Chemistry, for he has published many scientific papers. Allow me to present Newcomb K. Chaney, Ph.D., Director of Research, United Gas Improvement Company, Philadelphia, Pa., to receive the Howard N. Potts Medal, 'in consideration of his original and successful work in the hitherto uncharted field of carbon activation.'"

Mr. Staples: "We are happy to have you in Philadelphia and especially pleased to pay tribute to your achievements."

Dr. Chaney: "Many thanks for your kindness."

To H. Jermain Creighton, Sc.D., Professor of Chemistry, Swarthmore College, Swarthmore, Penna. Mr. C. H. Masland, 2nd, Sponsor.

Mr. Staples: "Mr. Masland."

Mr. Masland: "The Committee has recommended also the award of a Potts Medal to another outstanding chemist—one who, in the midst of a busy academic life, has found time to achieve distinction in the field of research. I have much pleasure in presenting to you, Mr. President—Dr. H. Jermain Creighton, Professor of Chemistry, Swarthmore College, Swarthmore, Pa., to receive this award 'in consideration of his distinguished work in developing a process for the electrolytic reduction of simple sugars on a large scale.'"

Mr. Staples: "It's a keen pleasure, Dr. Creighton, to make this presentation to you."

Dr. Creighton was most appreciative.

PRESENTATION OF CRESSON MEDALS.

To George Ashley Campbell, Ph.D., Research Engineer (Retired), American Telephone and Telegraph Company, New York City. Dr. Thomas D. Cope, Sponsor.

Mr. Staples: "The Chair now recognizes the sponsor for the Cresson Medal."

Dr. Cope: "Mr. President, the Elliott Cresson is one of the oldest and best known awards of The Franklin Institute. It was founded in 1848 and is awarded for distinguished contributions in the realm of physical science. The Committee, after thorough investigation, with full confidence, asks that this medal be awarded to Dr. George Ashly Campbell, Montclair, New Jersey, Retired Research Engineer, American Telephone and Telegraph Company, 'in consideration of his lifelong study of the theory of electric circuits, resulting in notable contributions to the science that underlies telephony and in inventions of fundamental importance in the art.'—Dr. Campbell."

Mr. Staples: "Dr. Campbell, no one in The Franklin Institute could have as much pleasure in giving you this medal as I have. You and I are of the same organization; it therefore gives me the greatest pleasure to hand you this medal and the certificate and report which accompany it.

Dr. Campbell smiled his appreciation.

To John R. Carson, D.Sc., Research Mathematician, Bell Telephone Laboratories Inc., New York City. Mr. Stuart Ballantine, Sponsor.

Mr. Staples then called upon Mr. Ballantine.

Dr. Stuart Ballantine: "The Committee has also recommended the award of a Cresson Medal to another laborer in the laboratories in the great field devoted to the extension of the human voice. I ask Dr. John R. Carson, Research Mathematician, Bell Telephone Laboratories, New York City, to come forward to receive this honor 'in consideration of outstanding contributions to the art of electrical communication.'"

Mr. Staples: "What I said about Dr. Campbell's award might be said also to Dr. Carson. I hand you this medal, the certificate, the report."

Dr. Carson expressed his appreciation for this recognition.

To Sir Charles Vernon Boys, London, England. Dr. C. B. Bazzoni, Sponsor.

Mr. Staples: "Dr. Bazzoni, please."

Dr. Bazzoni: "I present, in absentia, for a Cresson Medal, Sir Charles Boys, a noted scientist in London, England. He writes: 'I should have liked immensely to have come to receive

the medal personally and to have enjoyed the hospitality you offer, but I am now in my eighty-fifth year, in good health it is true, but hardly equal to such a journey. In addition, I am tied by my latest contribution to science, not yet published, to which I am giving all my time.'

"I quote this because I thought you would be interested to know why our oldest medalist isn't here. The award is made, 'in recognition of the scientific achievements of Sir Charles Vernon Boys, which have furnished scientists with new and remarkably precise methods for making measurements in gravitation, in sound, in heat, in radiation, in current and static electricity so refined as to render possible the weighing of the earth, the determination of the radiant energy coming to us from the stars, the photography of the speeding bullet, and the immobolization, even, of the lightning flash itself.'

"I have the honor now to present to you, Sir, Mr. Frederick Watson, British Consulate General in Philadelphia, to receive the medal on behalf of Sir Charles."

Mr. Staples: "Sir Charles must be a delightful person. I hand the medal to you, Mr. Consul General, and ask that you forward it to him, with expressions of our high esteem.

"We appreciate your kindness in participating in our programme today."

Mr. Watson: "I have particular pleasure in accepting the Cresson Gold Medal on behalf of Sir Charles Vernon Boys, F.R.S., because I had the pleasure of meeting him last summer at a dinner of the Royal Society at the Athenæum. He is a charming gentleman and in excellent trim, in spite of his eighty-five years. I had been invited to the dinner by Sir Albert Seward who represented the Royal Society at the Franklin Memorial celebration last May (1938).

"As I think I have stated before on a similar occasion, I am gratified at the metallic content of the Medal which is being presented, and feel that we are back in the days of Solomon when, as you will find in the twenty-first verse of the tenth chapter of the First Book of Kings: 'All King Solomon's drinking vessels were of gold, and all the vessels of the House of the Forest of Lebanon were of pure gold; none were of silver; it was nothing accounted of in the days of Solomon.'"

PRESENTATION OF FRANKLIN MEDALS.

Posthumously, to Albert Sauveur, Sc.D., D.Eng., Professor Emeritus, Metallurgy and Metallography, Harvard University, Cambridge, Massachusetts. Dr. James Barnes, Sponsor.

Mr. Staples: "The Chair calls upon Dr. James Barnes to present the Franklin Medalists of the day."

Dr. Barnes: "Mr. President: The Board of Managers of The Franklin Institute, on the recommendation of its Committee on Science and the Arts, is unanimously of the opinion that the two Franklin Medals be awarded this year as follows: One, posthumously, to Dr. Albert Sauveur—'In recognition of his outstanding work in the science of Metallography, and of his many contributions to this branch of metallurgy which have been in a large measure responsible for changing the heat treatment of steel from an art to a science.'

"Dr. Sauveur was born in Louvain, Belgium, in 1863 and came to this country after completing his preliminary education in the School of Mines at Liège. In 1889 he graduated from Massachusetts Institute of Technology and after serving with the Pennsylvania Steel Company and the Illinois Steel Company, was appointed Instructor in Metallurgy at Harvard and rose rapidly to become Professor in this field. This position he held until his retirement from active teaching in 1935.

"Dr. Sauveur was one of the early workers in the microscopic study of polished specimens of steel and in the taking of photomicrographs of such specimens. He showed that the physical properties of steel were largely dependent upon its grain sizes and that the dimensions of these resulted from the finishing temperatures and by alloying the iron with carbon and various metals. It is the study of these alloys under different heat treatments which constitutes the science of metallography to which Dr. Sauveur contributed so much of value.

"The list of honours conferred upon Dr. Sauveur is a long one. I wish to mention a few of these. During the war he was Director of Research for the Metallurgical Division, Air Service, American Expeditionary Force. He was an Officer of the Legion of Honor of France, an Officer of the Order of

Leopold of Belgium and the recipient of the Cresson, the Bessemer and the Albert Sauveur Achievement Medals.

"Mr. President, It was with sincere regret that your Committee heard of the death of Dr. Sauveur on January 26, 1939, and as this Committee wishes to honor the work of this distinguished scientist and educator, we ask you, Sir, to give our highest award, The Franklin Medal, to Mrs. Sauveur, who has been kind enough to come and be with us today. I present Mrs. Sauveur."

Mr. Staples: "Mrs. Sauveur, we are most grateful to you for coming here today to receive this acknowledgment of the distinguished achievements of your honored husband."

Mrs. Sauveur received the Medal and bowed, while the audience stood in silent tribute.

To Edwin Hubble, Ph.D., D.Sc., LL.D., Mount Wilson Observatory, Carnegie Institution of Washington, Pasadena, California. Dr. Barnes, Sponsor.

Dr. Barnes: "Mr. President: By the same authority, the other Franklin Medal be awarded to Dr. Edwin Hubble—'In recognition of his extensive study of the nebulæ, particularly those outside our galaxy, as a result of which the dimensions of observed space have been greatly increased.'

"Dr. Hubble was born in Marshfield, Missouri, in 1889. His collegiate education was obtained at the University of Chicago and he was appointed a Rhodes Scholar. He spent three years at Oxford, at the end of which he received the degree of Bachelor of Arts in Jurisprudence. In 1917 he earned the degree of Doctor of Philosophy from the University of Chicago. He then enlisted in the Army and after a year of service in France as a Major in the Infantry he returned home and was appointed on the Staff of Mount Wilson Observatory, which position he still holds.

"Working with the 100 inch telescope, Dr. Hubble undertook a comprehensive study of nebulæ in the region of the sky remote from the Milky Way. In these nebulæ he discovered many so-called Cepheid variables and from an accepted correlation between period and luminosity calculated their absolute luminosity, which in turn measures their distances from the Earth. The distances so found located the nebulæ well outside our galaxy.

"He also observed the changes in the wave-lengths of the radiations in the spectra of these nebulæ, the so-called 'red shift' as the absorption lines are shifted towards the red end of the spectrum, and by means of the Doppler Principle calculated their velocities in the line of sight. The velocities of recession were found to increase linearly with the distances of the nebulæ. In other words, he discovered, I think to his amazement, that the outer nebulæ consisting of billions and billions of stars larger than our Sun were running away from us and from each other with tremendous, even with explosive, speeds as much as 25,000 miles per second. Now results like these seem to confirm the theory of the expanding, or should I say, the exploding universe. I believe, however, that Dr. Hubble recognizes that his observations can be explained in other ways than by the Doppler effect, possibly by the one suggested by Professor Milne of Oxford, only a few days ago, at the dedication ceremonies of the new McDonald Observatory.

"On account of his brilliant and valuable experimental work, he has been the recipient of many honors, including the Barnard and the Bruce gold medals.

"Mr. President, I have the honor and pleasure of presenting to you one of the world's leading cosmologists—Dr. Edwin Hubble."

Mr. Staples: "Dr. Hubble, it is my privilege as President of The Franklin Institute, to hand to you the Franklin Medal, together with a Certificate of Honorary Membership in this old society. May I express our keen appreciation of your kindness in taking the long journey in order to be with us today, to receive your medal and present your paper, 'The Motion of the Stellar System Among the Nebulæ.'"

Dr. Hubble then expressed his gratitude for the honor paid him and presented an original paper on a portion of his work. This paper, under the title given above, appears in its entirety in this issue of the JOURNAL.*

There being no further business, the meeting adjourned, after an invitation from the President to the visitors to view the hundreds of exhibits in the museum.

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*Page 131.

MEDAL DAY DINNER.

At seven-thirty on the evening of the same day a dinner in honor of the medalists of the afternoon was served in Franklin Hall, at which approximately two hundred and fifty guests were present.

Mr. Staples, President of The Franklin Institute, acted as toastmaster.

Dr. Hubble, Franklin Medalist of the afternoon, gave an interesting talk. A musical programme, featuring the Franklin Song, was presented by Mr. Guy Marriner, in charge of the music section of The Institute. Dr. Henry Butler Allen, Secretary and Director, reported on the activities of the Institute for the year, and pointed out the progress which had been made in various directions.

LIBRARY NOTES.

The Committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The cost for a print 9 × 14 inches is forty cents.

The library and reading room are open daily from nine o'clock A.M. until five o'clock P.M. Saturdays until 12 o'clock noon. 677 readers made use of the facilities during the twenty-six days of June.

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NOTES FROM THE BARTOL RESEARCH FOUNDATION.

MEASUREMENT OF THE RADIO-FREQUENCY VOLTAGE IN A CYCLOTRON.*†

BY

W. E. DANFORTH AND M. B. SAMPSON.

Three methods have been devised for the measurement of the radio-frequency voltage which is applied to the accelerating electrodes ("dees") of a cyclotron.

The first method was one suggested by Professor W. F. G. Swann. The principle involves measurement of the magnetic field in the immediate vicinity of one of the conductors leading to the dees, and of obtaining thereby the current in the conductor. The magnetic field is determined by utilization of a small coil placed with its plane perpendicular to the lines of magnetic force and with its center at the point where the magnetic field is desired. The coil forms the inductance element of a simple circuit, whose other element is a capacity in series with it. The magnetic field is determinable immediately from the current in the coil circuit at resonance and from the resistance corresponding to the frequency. The resistance may be obtained without any further assumption by the usual method of measuring the current at resonance and also with a value of capacity differing slightly from that corresponding to resonance. The resistance may be obtained also by making two measurements of the current at resonance, the first being made with the normal high frequency resistance of a circuit, and the second, after the addition of a known resistance of a type unaffected by frequency. Still another method involves using permanently in the circuit a known high frequency resistance R sufficiently great to dominate the

* This study was made on the cyclotron of the Biochemical Research Foundation of the Franklin Institute built by Dr. A. J. Allen and Dr. M. B. Sampson and located at the Bartol Research Foundation of the Franklin Institute.

† Condensed from a paper published in full in the *Review of Scientific Instruments*, **9**, 175 (1938).

resistance of the circuit and so to render negligible the variation of resistance with frequency of that part of the circuit which is subject to such variation. This was the method used in practice. It has the further advantage of providing for a broad resonance and so for ease in measurement of the resonance current. Having determined the current by this method, and knowing the capacity of the dee into which the current is flowing, the voltage which the dee attains can be computed.

The second method consists in arranging a test electrode near one of the dees and noting the current as recorded by a thermal ammeter connected between said electrode and the grounded vacuum tank. With cyclotrons as they are at present designed it is unnecessary to incorporate a special electrode for this purpose; one already has a suitable placed conductor in the "deflector plate," the electrode by which the final ion beam is pulled clear of the dees. A relation between measured current and dee voltage is derived in terms of coefficients of capacity and induction. The necessary coefficients may be evaluated by means of three measurements with a capacity bridge or equivalent device.

The third method makes use of a well known principle in which a diode rectifier and condenser are connected in series between the conductor whose voltage is being measured and ground. The condenser becomes charged to the peak voltage of the conductor. Measurement of the voltage on the condenser is effected by means of a high resistance and a microammeter.

For various practical reasons none of the above methods is convenient for continuous use during operation of the cyclotron. As is the practice elsewhere, we have installed two small test electrodes in the vacuum chamber, one for each dee. Between each of these and ground is connected a radiofrequency transformer with a tuned secondary, the output of which is rectified with a small diode and fed through a suitable resistance to a milliammeter in the control room. Any one of the three methods described above serves to calibrate the scales of these milliammeters, a calibration which must be repeated whenever one changes the positions of the dees with respect to the test electrodes.

RADIOACTIVITY OF Be^7.*

BY

R. B. ROBERTS, N. P. HEYDENBURG † AND G. L. LOCHER.

As reported at the Washington meeting of the American Physical Society [1] we have obtained evidence for the formation of Be^7 in the reaction $Li^6 + H^2 \rightarrow Be^7 + n$. At that time we had found that there was no radioactive emission of charged particles. We have since discovered a gamma-ray radioactivity with a 43-day half-life in lithium targets which have been bombarded by deuterons. Further experiments indicate that the gamma-ray activity originates in K electron capture by Be^7 which leaves the residual Li^7 nucleus in the 450-kv. excited level.

The activity was first observed in a LiF target which had been bombarded a month previously with 35 microampere hours of 1000-kv. deuterons. Similar activity was subsequently produced by bombarding a lithium metal target with 20 microampere hours of 1000-kv. deuterons. The activity was followed for a month and showed a half-life of 43 ± 6 days. The absorption-coefficient in lead was 0.169 g. cm.$^{-1}$. No charged particles could be detected either by thin-walled counters, by ionization chambers, or by placing the sample in a cloud chamber, although the gamma-ray counting rate indicated the emission of more than 100 quanta per second.

The surface of the target (in which the activity was concentrated) was scraped off and subjected to a chemical separation, carried out by Dr. M. H. Van Horn of George Washington University. The activity was concentrated in the final precipitation of 100 micrograms of beryllium carbonate which had been added as a carrier. The separation would not, however, remove iron or aluminum. As iron also shows a 40-day period, we bombarded an iron target and looked for a similar gamma-ray. The iron impurity necessary to produce the observed gamma-rays from the lithium targets is greater than 100 per cent.

* Reprinted from the *Physical Review*, 53, 1016 (1938).

† Drs. Roberts and Heydenburg are members of the staff of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D. C.

[1] R. B. Roberts and N. P. Heydenburg, Abstract No. 78, 1938 Washington Meeting American Physical Society.

Although we were not able to detect the alpha-particle group produced in the reaction [1] $B^{10} + H^1 \rightarrow Be^7 + He^4$, we have since observed a long period gamma-ray activity from a B_4C target which had been bombarded with 11 microampere hours of 950-kv. protons. The intensity of the radiation was 25 per cent. less than that produced in the lithium metal target. Its absorption-coefficient was also 0.169 g. cm.$^{-1}$. We therefore ascribe both this activity and that produced in the lithium targets to Be^7.

This unusual type of radioactivity could originate in two nuclear reactions. Either a positron is emitted with so little energy that it does not ionize appreciably and is detected only by the annihilation radiation, or a K electron is captured and the residual nucleus is left in an excited state. In the latter case the average number of quanta per disintegration is less than one because there exists the alternative process of capture in which the nucleus is left in the ground state. Assuming as usual that a neutrino is emitted, these reactions may be written:

$$Be^7 \rightarrow Li^7 + e^+ + \eta$$
$$e^+ + e^- \rightarrow h\nu + h\nu \qquad h\nu = 0.5 \text{ Mev.}$$
$$Be^7 + e_k^- \rightarrow Li^7 + \eta \qquad \text{neutrino energy} = E \text{ Mev.}$$
$$Be^7 + e_k^- \rightarrow Li^{7*} + \eta \qquad \text{neutrino energy} = E - 0.45 \text{ Mev.}$$
$$Li^{7*} \rightarrow Li^7 + h\nu \qquad h\nu = 0.45 \text{ Mev.}$$

The absorption-coefficient in lead of the gamma-rays from the lithium targets and of the annihilation radiation of the positrons from N^{13} were measured under idential conditions and were observed to be 0.169 ± 0.008 and 0.130 ± 0.002 g. cm.$^{-1}$, respectively. This indicates that the energy of the radiation is 425 ± 25 kv., which agrees well with the energy expected from K electron capture but differs from the energy of annihilation radiation.

A comparison of the numbers of quanta observed per neutron emitted from the carbon and lithium targets gives additional information about the process. Li^6 and Li^7 are (per atom) equally effective in producing neutrons at 800 kv. and the yield curves for the two reactions are known.[2] The

[2] L. H. Rumbaugh, R. B. Roberts, and L. R. Hafstad, to be published shortly in *Phys. Rev.*

energy distribution of the neutrons from Li^6 shows that approximately one atom of Be^7 is formed for every two neutrons emitted. In carbon one neutron is emitted for each N^{13} atom formed. The comparison of the number of neutrons emitted by lithium and carbon has been made by Amaldi, Hafstad, and Tuve.[3] Thus the relative numbers of Be^7 and N^{13} atoms can be calculated. Assuming two quanta per N^{13} we find that, on the average, one quantum is emitted for each 10 Be^7 atoms produced. Positron-emission should lead to a gamma-ray intensity 20 times greater than that observed. On the other hand the data are consistent with the hypothesis of K electron capture, because in this case transitions to the ground state should be more probable than transitions to excited levels.

As a final check we have looked for double coincidence counts. No appreciable change in the background rate of 0.8 per minute was observed although the simultaneous emission of two quanta at 180°, which would be expected if positron annihilation occurred, should increase the rate by at least a factor of three.

THE MULTIPLICATIVE THEORY OF SHOWERS AS APPLIED TO LARGE BURSTS OF COSMIC-RAY IONIZATION.*

BY

C. G. MONTGOMERY AND D. D. MONTGOMERY.

In order to decide whether the multiplicative theory of showers offers an adequate explanation of the experimental data on large showers, or whether it is necessary to suppose that they are produced by some other process, such as has been outlined by Heisenberg, the following calculations are undertaken. The energy spectrum of the electrons and photons incident upon a small thickness of material is calculated from the observed frequency distribution in size of bursts of ionization produced by large showers, the effect of fluctuations being taken into account. The energy distribution obtained is of the form $E^{-\alpha}$, where α is 2.6 for energies of the

[3] E. Amaldi, L. R. Hafstad, and M. A. Tuve, *Phys. Rev.*, **51**, 896–912 (1937).

* An abstract of a paper published in full in the *Physical Review*, **53**, 955 (1938).

order of 10^9 volts, and decreases slowly with increasing energy, in agreement with the energy distribution calculated by Heitler to explain the variation of cosmic-ray intensity with altitude. The maximum number of electrons necessary to give the observed frequency of bursts is less than 0.5 per cent. of the total number of particles observed in a cloud chamber at sea level in the energy range between 10^9 and 10^{10} volts, which is in good accord with the cloud chamber observations. This calculated incident energy spectrum is utilized to calculate the number and frequency distribution of large bursts for large thicknesses of material. These calculated values differ considerably from the experimental ones, but this difference is probably to be ascribed to the effect of the penetrating cosmic rays, and is not to be regarded as evidence of a breakdown of the cascade theory. The experiments on the absorption of a shower are also shown to be in harmony with the theoretical estimates. It is concluded that no mechanism involving the production of many shower particles in a single act need be invoked to explain the occurrence of large showers, but that the ordinary multiplicative processes are entirely adequate when proper account is taken of the fluctuations.

CIRCUITS FOR THE CONTROL OF GEIGER-MUELLER COUNTERS AND FOR SCALING AND RECORDING THEIR IMPULSES.*

BY

T. H. JOHNSON.

This paper is not suitable for condensation in Note form. It will suffice to say that an analysis is given of the controlling action of a vacuum tube in circuits similar to those proposed by Neher and Harper and Neher and Pickering. A modification of the latter's circuit eliminating some of its disadvantages is described. This circuit has been incorporated into a four tube network which controls the counter, scales down the impulse rate by any desired factor, and records the scaled counts. A new circuit is also described for recording the impulses from a single counter or from counters connected in coincidence.

* An abstract of a paper published in full in the *Review of Scientific Instruments*, 9, 218 (1938).

The topics dealt with are discussed under the following heads:

1. Analysis of counter control circuits.
2. A combined scaling and control circuit.
3. Counter control and scaling circuit for coincidence counting.
4. A neon tube coupled multivibrator delay circuit for recording single or coincidence counter pulses.

COSMIC-RAY ELECTRON SHOWERS IN A MINE 100 FEET BELOW SEA LEVEL.*

BY

W. F. G. SWANN AND W. E. RAMSEY.

The apparatus comprised essentially four trays of cosmic-ray counters, arranged parallel to one another, and separated by distances, so that the whole formed a kind of telescope.

The records were obtained upon moving photographic paper, in which, along the central axis, was recorded in the form of dark lines each "event" which we define as the simultaneous discharge of at least one counter in each of the four counter areas. Above and below the center portion was recorded, in the form of electroscope deflections, a quantity indicative of the number of individual rays passing through the upper and lower of the two central counter areas, and corresponding to an "event." Figure 1 is a sample of the kind of record obtained; and in all about 300 feet of such records were obtained, covering cases (1), where there was no lead in the apparatus, and (2), where above each of the central trays a slab of lead 6 mm. in thickness was inserted.

In the absence of the lead, it was found that, on the average, the number of showers of any size per single ray was practically the same in the mine as in the attic of our Swarthmore laboratory, where the apparatus was covered by thick slabs of marble, to duplicate the conditions in the roof of the mine.

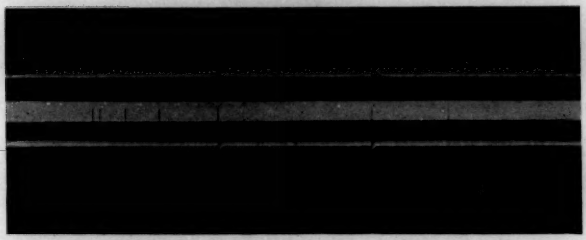
Again in the absence of lead, it was found that, on the average, the total number of rays (as obtained from the

* Reprinted from the *Physical Review*, 54, 229 (1938).

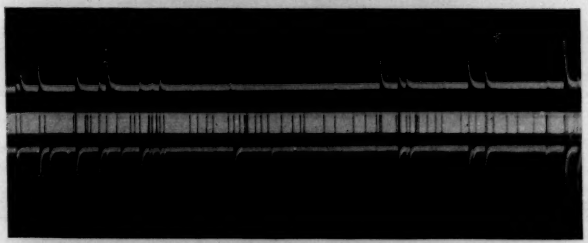
FIG. 1.

TYPICAL HALF HOUR RECORDS

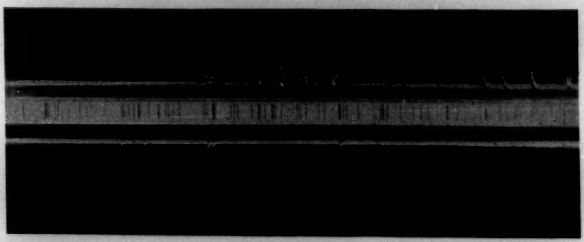
IN MINE



SEA LEVEL - UNDER ROOF



SEA LEVEL - OPEN AIR



The heights of peaks indicate numbers of rays. All of these photographs taken without lead in the apparatus.

showers) passing through the telescope system was 1.6 times the number of "events." It is of profound interest to determine, if possible, whether the extra rays are or are not electrons. In order to obtain information on this matter, we have made use of the experiments with lead. Let A be the upper piece of lead and B the lower. It was found that the ratio of the total number of shower rays emerging from B to the number emerging from A was 1.3, where, by the number of shower rays in each case, we mean the number of rays in excess of the number of single rays which are always associated with any recorded "event."

We may now make the tentative hypothesis that the hard component rays do not produce showers appreciably in the lead, and ask what the average energy of a group of electrons would have to be in order that, through the processes of the quantum theory, they would result in the production of showers in the lead such as to give the ratio 1.3 cited above. The answer is 2×10^8 ev. We may then ask how many of such electrons would have to enter the piece of lead A per hour in order to produce, on emergence from that piece of lead, the number of shower rays found per hour. The answer is 7. This is approximately equal to 7.5, which represents the difference between the total number of rays recorded per hour *in the absence of the lead*, and the number of "events" recorded. Thus, there is harmony between the experiments and the assumption that each "event" is associated with one hard ray, which rays themselves produce negligible showers in the lead, but which are accompanied by electrons to the extent of 1.6 of their number and of energy 2×10^8 ev.

Although the experiments are consistent, to a first approximation, with neglect of direct shower production by the hard component rays in the lead, we must, nevertheless, assume that it is the showers produced by the hard component in the substance of the earth which, in actuality, represent the electrons found in the mine, since neither primary cosmical electrons of reasonable energy nor their progeny produced by multiplication could penetrate to the depths concerned. It is natural to regard the hard component shower phenomenon as one occurring at rare intervals, possibly with the ejection, on these occasions, of a few or even one particle with high energy.

If this particle is an electron, or gives rise to electrons, these electrons, through the ordinary quantum theory processes, may be expected to constitute or to give rise to such shower producing electrons as were to be found in the mine.

The writers wish to express appreciation of the assistance afforded by a grant from the American Association for the Advancement of Science.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Gravimetric Microdetermination of Selenium in Organic Compounds.—HERBERT K. ALBER AND JOSEF HARAND. (Microchemical Department of the Biochemical Research Foundation of The Franklin Institute, Philadelphia, Pa.) Organic selenium compounds are of theoretical and practical interest due to the similarity of selenium to sulfur in its chemical behavior. Selenium, either as the free element or in combination, exhibits important physiological effects and marked toxicity when introduced into the animal organism (H. C. Dudley, U. S. Public Health Reports, **53**, 281 (1938)). Its highly injurious properties have been strikingly demonstrated in the "alkali disease" of Western cattle.

Comparatively few micromethods are known for the analysis of selenium in organic compounds where selenium is one of the major constituents. The procedures of Wrede (*Chem. Ztg.*, **44**, 603 (1920); *Z. physiol. Chem.*, **109**, 272 (1920)) and of Drew and Porter (*J. Chem. Soc.*, **1929**, 2091) are perhaps more generally applicable than most others. The former combusted the substance in a current of pure oxygen, as is done in Pregl's catalytic method for sulfur (H. Roth and E. B. Daw, "Quantitative Organic Microanalysis of Fritz Pregl," 3d English Edition, P. Blakiston's Son and Co., Philadelphia, 1937, pp. 120 ff.), and titrated the selenious acid formed with N/100 NaOH. Drew and Porter decomposed the sample with nitric acid in a Carius tube and weighed the selenium in its elementary form after reduction with sulfur dioxide. A detailed study of these two methods has led to the development of a procedure which combines some of the best features of each.

Decomposition of the Organic Sample.—It was found that Pregl's catalytic combustion procedure, using a spiral or bead tube, provided the most suitable type of decomposition for the organic sample. Since combustion is carried out by means of a current of pure oxygen, and the combustion

products are absorbed in water, the method introduces no foreign material which might interfere at a later stage. Also, the combustion is quite easily performed, and other elements such as nitrogen, halogens, sulfur, and arsenic, do not interfere.

The *Carius* decomposition, as used by Drew and Porter, gives accurate results only in the absence of halogens; it furthermore introduces a considerable amount of nitric acid, and is somewhat time-consuming and rather complicated.

Reduction to Elementary Selenium.—When organic selenium compounds are combusted in oxygen as described above, selenious acid results. In the procedure of Wrede the acid is titrated with N/100 NaOH, using methyl orange as indicator. This method is not applicable in the presence of halogens nor of nitrogen, since these elements form acid combustion products. Drew and Porter reduce the Carius digest with sulfur dioxide without removing the nitric acid and weigh the elementary selenium. The most satisfactory procedure which we have found has been the reduction of the selenious acid formed by means of SO_2 in hydrochloric acid (40 per cent. HCl by volume). It has been stressed in the literature, and confirmed by our experiments, that the conditions of the reduction to the elementary form must be carefully controlled in order that selenium losses may be avoided. The detailed instructions, as given below, must be followed closely if results within the established limits of accuracy are to be obtained. The proper conditions for the reduction have been carefully checked by means of special tests; e.g., we believe that sulfur dioxide is the purest and best reducing agent under the given conditions (other substances tried by us were hydrazine and hydroxylamine).

Filtration and Weighing.—It is obvious that weighing of the selenium in its elementary form is not a completely satisfactory procedure from a quantitative viewpoint. Any error in weighing, or any inconstancy in the weight of the filtration vessel, will influence the accuracy of the method to a high degree. This error can be kept within the limits of accuracy of the method by taking such an amount of sample that at least 2 mg. of selenium will be collected on the filter layer.

The selection of Pregl's filter tubes with asbestos layers

instead of sintered glass plates, as commonly used in halogen determinations, was governed by the following observations:

(1) The finely powdered selenium precipitate enters the capillaries of the fritted glass disk and the filtering layer remains efficient for one determination only. In a series of gravimetric determinations it is desirable to have the tube, with the precipitate, available immediately after the weighing, for the collection of a second precipitate, thus eliminating one of the rather time-consuming weighings.

(2) If, for purposes of cleaning, the selenium is dissolved in Na_2S, the highly alkaline solvent influences the sintered glass plate in such a way that even after 4 to 6 consecutive washing procedures with hydrochloric acid, water and alcohol, and drying, the weight of the tubes diminishes by 40 to 100 μg. Since constancy of the tubes within 5 μg. is a major requirement, filter tubes with an asbestos layer only are used and special precautions are taken against moisture changes in the filter medium. Obviously, an acid solvent such as 40 per cent. hydrobromic acid containing 0.5 per cent. free bromine would help to overcome these difficulties, but this solvent has other disadvantages (price, odor, preparation).

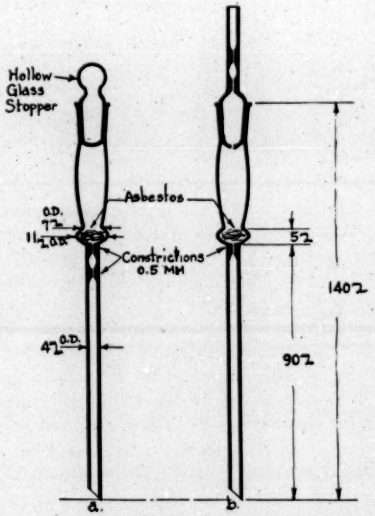
The asbestos filter tubes of Pregl with two constrictions in the stem and ground-in hollow glass stopper, Fig. 1, *a*, are commonly used for the weighing of *hygroscopic* precipitates, as, for example, in the phosphorus determination by Lieb. This tube was found to be easier to handle, and it attains constant weight more rapidly than the one described by Drew and Porter, which is shown for comparison in Fig. 1, *b*. (The latter has been incorrectly interpreted in the literature to be the "micro Gooch-crucible." (H. Meyer, "Analyse und Konstitutionsermittlung organischer Verbindungen," 5. Auflage, J. Springer, Berlin, 1931, p. 206.).)

Emphasis must be placed on cleanliness of all reaction vessels, siphon tubes, and filter tubes used, so that any mechanical losses of selenium may be prevented.

Selenium compounds must be weighed with utmost care, since deposition of dark decomposition products on the various parts of the microchemical balance has been observed in some instances. Several selenium compounds exhibit a disagreeable odor. Therefore, it is advisable to weigh solid

compounds in the charging tube with ground cap, and liquid compounds in weighing capillaries filled by the automatic procedure in the test tube with side arm according to Alber (*Mikrochemie (vereinigt mit Mikrochimica Acta)*, **25**, 47, 167 (1938)).

The method of analysis described as follows is a combination of the procedures by Wrede and Drew-Porter with some minor modifications.



Filter tubes for hygroscopic precipitates. (½ actual size.)
a—standard
b—Drew and Porter

Procedure.—5 to 20 mg. of the solid sample, containing from 2 to 5 mg. selenium, are transferred into a porcelain boat. If the substance be hygroscopic, one of the procedures described by Alber is followed. Liquid samples are weighed in capillaries. The free end of the capillary, the tip of which is broken off just before the introduction into the combustion

tube, is directed *against* the current of oxygen. The spiral or bead tube of Pregl is carefully cleaned, rinsed with distilled water and left moist for the combustion. A small test tube is placed over the end with the spiral part, and the platinum catalyst in the form of stars or cylinders is introduced. The catalyst should be slightly etched with aqua regia before each determination.

The combustion itself is carried out in a current of oxygen, about 5 to 6 ml. per minute, to prevent the passage of uncombusted carbonaceous material over the catalyst. The danger of backsublimation due to the slow speed of the gas current is counteracted by placing a second Bunsen burner at about 5 cm. distance from the first towards the entrance end of the spiral tube. The time for one combustion will depend upon the amount of sample and will be between 45 and 70 minutes. If the combustion be carried out properly the selenious acid will appear as fine needles in the dry parts of the tube near the heater. An electric furnace is used to advantage in this laboratory.

After cooling, boat and platinum contacts are removed, and the tube is washed with distilled water which has been colored with methyl orange. The completeness of the washing-out of all acid reaction products can be controlled in this simple way. The washings are collected in a 40 × 100 mm. test tube with a graduation mark at 25 ml. The volume of the solution is brought to this mark with distilled water; 14 ml. of concentrated HCl, which has been previously saturated with sulfur dioxide, are added in the cold, so that the concentration of HCl in the final solution is from 35 to 40 per cent. by volume. Then, the solution is heated on a water bath (the temperature should remain close to, but below 100° C.) for 20 minutes, a lively stream of SO_2 being passed through meanwhile from a 1 mm. wide capillary tip. The gas is taken directly from a sulfur dioxide tank after passing through a cotton filter. The color of the solution changes to reddish (colloidal selenium); after a while a black precipitate appears and the supernatant liquid becomes clear, but remains red from the methyl orange of the wash water. The solution is cooled by placing the reaction vessel in ice water for 30 to 60 minutes; apparently, standing over night does not affect the results.

The filter tube, Fig. 1, *a*, is brought to constant weight by washing with HCl saturated with SO_2, with distilled water, and alcohol three times each. It is dried for 10 minutes at 115° C. in Pregl's drying block, and, with the glass stopper in place, is ready for weighing 20 minutes after wiping. A constancy within 5 μg. should be obtained after repeating this treatment.

The selenium precipitate is siphoned onto the asbestos layer of the filter tube, a complete transfer being secured by intermittent washing of the precipitation vessel with distilled water and alcohol. The filter tube is dried and weighed as described above. The final weight of the tube can be used as the first weight for a subsequent determination, note being taken of any changes in the zero reading of the microchemical balance. A filter tube can be used, without removal of the selenium, for about 6 determinations, i.e., until about 25 to 30 mg. of selenium have accumulated on the asbestos filter layer.

Results.—The accuracy of the method has been found to be within 0.3 per cent. by combusting copper selenite in the manner described above. The purity of this sample was checked by direct selenium determinations and electrolytic deposition of the copper from the filtrate. It was found to be 99.1 per cent. pure with respect to the selenium content; for the results see Table I. Other standard samples used were Diphenylselenium Dichloride (Eastman Kodak Co.), recrystallized according to Lyons and Bradt (*Ber.*, **60**, 60

TABLE I.

Accuracy of Method.

Substance.	Purity.	Sample in mg.	Se found in mg.	Se found in %.	Se calc. in %.	Error in %.
Copper Selenite	99.1%	6.196	2.140	34.5	34.5	+0.1
$CuSeO_3 \cdot 2H_2O$		8.245	2.835	34.4	—	−0.3
(Se calc.: 34.85%)		8.994	3.100	34.5	—	−0.1
Diphenylselenium Dichloride	100%	9.650	2.500	25.9	25.98	−0.3
		13.650	3.540	25.9	—	−0.2
$C_{12}H_{10}SeCl_2$		16.633	4.325	26.0	—	+0.15
Diphenylselenium	100%	10.375	3.510	33.8	33.88	−0.15
$C_{12}H_{10}Se$		17.105	5.815	34.0	—	+0.3

(1927)), and Diphenylselenium, fractionally distilled under reduced pressure according to Strecker and Willing (*Ber.*, **48**, 196 (1915)); the analyses of these compounds, as reported below, indicate a high degree of purity.

Some of the analyses on organic selenium compounds, taken from the routine analytical work in this laboratory, are reported in Table II. These substances, seleno-ethers and arsine-selenides, were synthesized in the organic department of the Foundation by A. Binz, F. E. Reinhart and

TABLE II.

Analysis of Organic Selenium Compounds.

No.	Compound.	Sample in mg.	Se found in mg.	% Se found.	% Se calc.	Nitrogen in %.	
						Found	Calc.
1	Bis (4-morpholylmethyl) selenide $C_{10}H_{20}O_2N_2Se$	14.679 25.142	4.115 7.015	28.0 27.9	28.3 28.3	9.88 9.84	10.0 10.0
2	3-Amino-4-hydroxy-phenyl-arsine-selenide $C_6H_6ONAsSe$	11.702 12.750	3.530 3.825	30.2 30.0	30.15 30.15	5.32 5.31	5.35 5.35
3	3-Amino-4-hydroxy-phenyl-arsine-diselenide $C_6H_6ONAsSe_2$	10.062 20.301	4.500 9.120	44.7 44.9	46.3 46.3	4.01 4.04	4.11 4.11
4	2-Pyridone-5-arsine-diselenide $C_5H_3NOAsSe_2$	9.097 10.422	4.290 4.915	47.2 47.2	48.5 48.5	4.18 4.22	4.30 4.30
5	3-Amino-2-pyridone-5-arsine-diselenide $C_5H_4N_2OAsSe_2$	8.407 9.356	3.705 4.135	44.1 44.2	46.3 46.3	7.74 7.65	8.22 8.22

H. C. Winter (work to be published). Unfortunately, most of them are unstable, sensitive to light and exceedingly difficult to purify. The precision of the method is within 0.3 per cent. as indicated by the duplicate analyses. The latter are a much better proof for the efficiency of the method than the deviations from the calculated values. For the purpose of comparison and evaluation of the purity of these compounds the nitrogen values are recorded in the same Table II. In addition, these nitrogen values prove that the

micro Dumas-method gives accurate results in the presence of selenium alone (Table II, No. 1) or together with arsenic (Table II, No. 2 to 5). Also, the presence of chlorine, besides arsenic and selenium, offered no difficulties in this determination.

The micro carbon and hydrogen determination of selenium compounds can be carried out with the ordinary tube filling (silver, platinum gauze, copper oxide, lead chromate, and lead peroxide), but it is advisable to use a special combustion tube for selenium compounds and replace it after about 40 determinations.

Diphenylselenium dichloride: $C_{12}H_{10}SeCl_2$.
Calc.: C = 47.38 per cent., H = 3.31 per cent.
4.568 mg. sample, 1.40 mg. water, 7.92 mg. CO_2;
C = 47.3 per cent., H = 3.43 per cent.
Diphenylselenium: $C_{12}H_{10}Se$: Calc.: C = 61.80 per cent.,
H = 4.32 per cent.
4.830 mg. sample, 1.83 mg. water, 10.93 mg. CO_2;
C = 61.7 per cent., H = 4.24 per cent.

The chlorine determination in selenium compounds is best carried out by the Parr microbomb method of Elek and Hill (*J. Am. Chem. Soc.*, **55**, 2550 (1933)). For example, a test analysis with o-chloro-benzoic acid was performed in the presence of about 5 mg. added bis (4-morpholylmethyl) selenide: 5.218 mg. sample gave 4.765 mg. AgCl. Cl found: 22.6 per cent.; Cl calc.: 22.66 per cent.

Diphenylselenium dichloride: $C_{12}H_{10}SeCl_2$.
Calc.: Cl = 23.33 per cent.
6.872 mg. sample, 6.50 mg. AgCl; Cl = 23.4 per cent.
5.601 mg. sample, 5.26 mg. AgCl; Cl = 23.2 per cent.

Studies on Proteinases of Some Anaerobic and Aerobic Micro-Organisms.—LEOPOLD WEIL, WALTER KOCHOLATY AND LOUIS DESPAIN SMITH. (*Biochemical Journal*, **33**: 893, 1939.) The proteinases of a number of spore-forming, anaerobic bacteria (*Clostridium botulinum*, *C. sporogenes*, *C. Welchii*) were studied, and found to be quite similar to the proteinase of *C. histolyticum*, which we described in a previous

paper (*Biochem. Journ.*, **32**: 1685, 1938). The proteinases of these organisms were activated markedly by sulfhydryl compounds, the effects of which were increased considerably by traces of heavy metals. The pH optima of these proteinases were at neutrality.

That a cell-free filtrate of a young culture of *C. Welchii*, without activation, could hydrolyze only gelatin and not clupein, has been reported (Maschmann, *Biochem. Zeits.*, **295**: 351, 1938). When activated by sulfhydryl compounds, this filtrate could hydrolyze clupein. A filtrate of a much older culture, in which the organisms were dead and undergoing hydrolysis, could hydrolyze clupein without activation. This problem was reinvestigated by us. A cell-free filtrate of a 16 hour culture of *C. Welchii* was used. At that time of incubation, practically all of the bacteria in the culture are living and dividing, and, consequently, any enzyme present in the filtrate may be presumed to have been produced extracellularly. The proteinase in the filtrate of this culture readily hydrolyzed all the investigated proteins, and was activated markedly by cysteine-Fe^{++}. The similar behavior of the enzyme-activator system toward the various protein substrates investigated did not indicate a number of proteinase actions, as had been suggested by Maschmann.

Recent investigations have indicated the possible importance of the sulfhydryl compounds for the peptidase system of anaerobic bacteria. Consequently, there was a possibility that the activation observed by us of sulfhydryl compounds on the proteinases of these organisms might be due to peptidases present in the culture filtrate. However, such an explanation did not hold for the proteinases investigated, since filtrates of 24 hour cultures were found to contain no peptidase whether tested in the presence or in the absence of the activator. Further evidence that the sulfhydryl activated the proteinase was given by the liquefaction of gelatin by the proteinase of *C. histolyticum*, followed by the viscometric method. By this method the very first steps of protein breakdown were measured, so any considerations of peptidase activity could be excluded. The liquefaction of gelatin by the *C. histolyticum* proteinase was activated

markedly by cysteine-Fe^{++}, indicating a purely proteinase action.

Our investigations were extended to include some aerobic micro-organisms. Cell-free filtrates of *Bacillus mycoides*, *Pseudomonas fluorescens*, *Staphylococcus citreus*, and *Serratia marcescens* contained proteinases which, although differing in their partial activation behavior, as a whole resembled the proteinases of the Clostridia. The addition of cysteine, which activated the proteinases of the Clostridia, produced, in the case of the aerobic organisms, a partial inhibition while Fe^{++} had an activating effect. Cysteine-Fe^{++} had the greatest activating effect. The pH optima of the proteinases of the aerobic micro-organisms were at neutrality.

The cell-free filtrates of the facultative organism, *Proteus vulgaris*, contained a proteinase which resembled the proteinases of the Clostridia in respect to activation behavior and pH optimum.

BOOK REVIEWS.

SPARKS, LIGHTNING, COSMIC RAYS, AN ANECDOTAL HISTORY OF ELECTRICITY, by Dayton Clarence Miller. 192 pages, illustrations, plates, 15 × 22 cms. New York, The Macmillan Company, 1939. Price $2.50.

Those who have attended the Christmas Week Lectures at The Franklin Institute are well acquainted with their tenor. Those who have been unable to attend know that because they are given under the words "In Honor of Benjamin Franklin" they are a worthy contribution toward the widest dissemination of knowledge, carrying on the practice which for many years has been that of The Franklin Institute. This book is a presentation of these lectures for young people. They appear here substantially as delivered orally; the difficulty of describing apparatus and the operation of the experiments, which in the oral lectures are transmitted visually, is overcome very nicely in an easily read and understood manner. Both the style and illustrations are admirably done.

The treatment of the subject matter is such that it bears much evidence of a great deal of thought and planning before it was molded into the finished product to fit the specific purpose—for young people. The general trend is that of a series of short stories which run smoothly, incidentally inculcating a surprising amount of technical descriptive matter of sufficient extent, but not excessive or burdensome. In fact this is so interwoven with the story, it is absorbed almost entirely without realization. While the lectures were directed to young people, there is no doubt that this book can and will have appeal to older persons as well, particularly those whose immediate interests and knowledge are removed from the circumference of the subjects. For both groups, the book is informative and adds to culture.

Under the subject of sparks, the history of man's observance of electrical phenomena is told from the earliest times up to the high potential electrostatic generators of today. The subject of lightning covers much of the work of Franklin in this field and contains reference to discoveries and knowledge resulting therefrom accomplished by Franklin but generally accredited to others. Little known work of Franklin is also revealed. The story of cosmic rays does a great deal in the way of facilitating understanding of a subject which is more and more coming before the public eye. It is one of the best illustrations of how the contributions of various scientists through history are added together to form a basis for work of present day investigators.

No one can doubt the wisdom of these lectures for young people. As adults of tomorrow, these youngsters will require a broader general scientific knowledge in order that the future common facilities and theories will be appreciated. This book can find use in every home.

R. H. OPPERMANN.

THEORETICAL AND APPLIED ELECTROCHEMISTRY, by Maurice de Kay Thompson. Third Edition, 535 pages, illustrations, 15 × 22 cms. New York, The Macmillan Company, 1939. Price $5.00.

Here is the third edition of this book, the first having been published in 1911. The title indicates a rather broad coverage, especially so when it is presented in the form of a text. That there is a need in this field for such a work cannot be doubted because the subject is one that is susceptible to treatment involving both theory and practice. There must however, be careful consideration given to prerequisites necessary for use and examination of this book. Exceptional knowledge must be had in chemistry, physics, and physical chemistry, for the average student. Once this is satisfied the book should fit well as a text and reference work.

There are three parts to the book. Beginning with theoretical electrochemistry involving such fundamentals as Faraday's law and electrolysis, electrolytic dissociation, elecktrokinetic phenomena, the treatment proceeds in the second part on applied electrochemistry of aqueous solutions such as electroplating extraction and refining of metals, and the electrolytic purification of water. Part three is devoted to rather complete theoretical and technical data on electric furnaces and their products. The immensity of the subject has required that little space be wasted in the book for shading off the topics covered. Facts are given straight from the shoulder and simply, and it is gratifying to find that in following the progression, the presentation taken as a whole is quite smooth if studied slowly with care and caution. But in spite of the need for conservation of space no sacrifice is made with regard to textbook characteristics. The problems at the end of the chapters contribute in no little degree toward impressionable understanding. The bibliographies listed here are undoubtedly of much assistance.

At the end of the book there are solutions to the problems and an index. The book should be of as much, if not more, use as a reference and text to workers in this field as to students since a large portion of it is devoted to practical industrial applications.

R. H. OPPERMANN.

THE MARCH OF MIND, A SHORT HISTORY OF SCIENCE, by F. Sherwood Taylor. 320 pages, illustrations, 15 × 23 cms. New York, The Macmillan Company, 1939. Price $3.00.

This book is a republication of that published in England under the title of "A Short History of Science." That title is more indicative of the contents than "The March of Mind," for it deals specifically with the history of science and scientific thought, and it is only in this sense that the latter title is used. The author states that his purpose is to show the changing attitude of men to science, and of science to the external world it studies. Taking this literally, it is no little task to undertake. It requires conclusions to be drawn from activities over long periods which necessarily must be influenced by a knowledge of succeeding events, whether rightly or no.

An examination of the work reveals that the basic part of the theme, the history of science, is well covered despite the immensity of the subject to be included in one book. It starts with the beginnings of science covering the logical

deductions from what remains of the story of primitive man. This leads into divisions of the book on the science of Greece, Eastern and Arabic science, Mediæval science, the Renaissance, the rise of modern science, and finishing with the age of science. The last subject contains a brief and interesting account of the conflict of science and religion in the nineteenth century, followed by the progress of science since 1850, the date terminating the previous subject, the rise of modern science. This is the general construction of the book. Obviously, only the high points of historic progression are noted, but the choice is admirably done. Furthermore, the unmistakeable definiteness of some statements of history smack of an intimate knowledge born only of exhaustive study and a great attachment to the subject.

Interwoven with the historical account are the references to the attitudes directed toward science and the study of the external world. These are the author's conclusions. It is too much to presume that authorities would reach complete agreement on all of these. Even with the great amount of original material available today, together with the suppositions of earlier workers, there is a very large portion of conclusions which must be a matter of opinion. The fact that one event occurred at a certain time which may have created a sensation is not necessarily proof that it lead to another event at a later date. The book should be read with this in mind if it is to be taken seriously and due allowance should be made.

The style of presentation is such as to be easy reading. At times the author apparently found it necessary to couple events a little too close but the progression generally is smooth. There is a breadth of compass covered that should add to the knowledge of the average reader.

R. H. OPPERMANN.

THE SOCIAL FUNCTION OF SCIENCE, by J. D. Bernal. 481 pages, plates, tables, 15 × 22 cms. New York, The Macmillan Company, 1939. Price $3.50.

For some years now, since the advent of the great economic depression there has been an increasing interest leading to agitation on the question of certain systems of knowledge concerning some subjects or groups of subjects. It will be remembered that one of the rises in interest of the subject of technocracy took place in this period. Subsequently technological unemployment, the patent system, and science itself came under scrutiny with respect to effects produced on the general welfare. The mere passing of the popular spot-light across these subjects and accusations against them does not mean that investigation has been abandoned. It has laid dormant. Technocracy, which has gone through at least one cycle of popularity proves this. Accumulation of the demands for more light at present takes the form of a much enlarged question on an equally enlarged subject—that of all scientific pursuits, and the demand is constantly rising so that the result has progressed in the mind of the general public to the extent of engaging the attention of government.

Scientists and engineers would do well to examine this great problem. The Social Function of Science is an attempt to investigate how the results of scientific knowledge have contributed constructively and destructively to human welfare. It is one man's viewpoint, a physicist's of England. He furnishes a foundation

for his theme in a brief historical account of science up through the World War and post war period showing the relationship of the social function. It is recorded that developments proceeded in a haphazard manner so that today there is inefficiency both as to internal scientific organization and in the application to problems of production or welfare. The destructive effects of science are described beginning with an interesting statement on "war research" and followed by military research, food supplies, chemistry in war etc. There is discussed science on an international scale, the application of science, science in education and other subjects pertinent to what science really does.

The second part of the book dwells on what science could do and here are the author's main conclusions. Interesting topics are the reorganization of research, the function of publications and the question, "Can science be planned?" Science is pictured as being an integral part both of the material and economic life of our times and of the ideas which guide and inspire it.

The book covers a very broad field. Certain sections bear very definite evidence of exhaustive study, on others it seems not enough has been said. On reading it, one is tempted to jump at conclusions on the correctness of general statements. It is not possible that an intelligent reader will agree on every point, but in-as-much as the views set forth are those of an individual, the book should be read, if for no other reasons than to gain a conception of the author's idea of the size of the problem as well as his stock of general information concerning it. The importance of the problem should not, by all means, be underestimated.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 652, Air Flow in the Boundary Layer of an Elliptic Cylinder, by G. B. Schubauer. 20 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

The boundary layer of an elliptic cylinder of major and minor axes 11.78 and 3.98 inches, respectively, was investigated in an air stream in which the turbulence could be varied. Conditions were arranged so that the flow was two-dimensional with the major axis of the ellipse parallel to the undisturbed stream. Speed distributions across the boundary layer were determined with a hot-wire anemometer at a number of positions about the surface for the lowest and highest intensities of turbulence, with the air speed in both cases sufficiently high to produce a turbulent boundary layer over the downstream part of the surface. The magnitude and the frequency of the speed fluctuations in the boundary layer were also measured by the use of the conventional type of hot-wire turbulence apparatus. Stream turbulence was found to affect both the nature of transition from laminar to turbulent flow in the layer and the position on the surface at which transition occurred.

Transition was then investigated in detail with stream turbulence of several different scales and intensities. It was found that the position of transition could be expressed as a function of the intensity divided by the fifth root of the scale.

Report No. 658, Tests of Two Full-Scale Propellers with Different Pitch Distributions, at Blade Angles up to 60°, by David Biermann and Edwin P. Hartman. 15 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

Two 3-blade 10-foot propellers were operated in front of a liquid-cooled engine nacelle. The propellers differed only in pitch distribution; one had normal distribution (nearly constant pitch for a blade angle of 15° at 0.75 radius), and the other had the pitch of the tip sections decreased with respect to that for the shank sections (blade angle of 35° for nearly constant pitch distribution). Propeller blade angles at 0.75 R from 15° to 60°, corresponding to design speeds up to 500 miles per hour, were investigated.

The results indicated that the propulsive efficiency at a blade angle of 60° was about 9 per cent. less than the maximum value of 86 per cent., which occurred at a blade angle of about 30°. The efficiency at a blade angle of 60° was increased about 7 per cent. by correcting for the effect of a spinner and, at a blade angle of 30°, about 3 per cent. The peak efficiencies for the propeller having the washed-out pitch distribution were slightly less than for the normal propeller but the take-off efficiency was generally higher.

PUBLICATIONS RECEIVED

Der Dispense Bau der Festen Systeme, von Prof. Dr. D. Balarew. 240 pages, illustrations, 16 × 24 cms. Dresden, Theodor Steinkopff, 1939. Price 8.62 R.M.

Engineering Opportunities, edited by R. W. Clyne. 397 pages, plates, 15 × 22 cms. New York, D. Appleton-Century Company, Inc., 1939. Price $3.00.

Proceedings of the Fifth International Congress for Applied Mechanics, held at Harvard University and the Massachusetts Institute of Technology, September 12–16, 1938, edited by J. P. Den Hartog and H. Peters. 748 pages, illustrations 23 × 29 cms. New York, John Wiley & Sons, Inc., 1939.

Uses and Applications of Chemicals and Related Materials, compiled and edited by Thomas C. Gregory. 665 pages, 16 × 24 cms. New York, Reinhold Publishing Corporation. Price $10.00.

Air Conditioning, Principles and Practice, by Burgess H. Jennings and Samuel R. Lewis. First Edition, 467 pages, illustrations, 16 × 23 cms. Scranton, International Textbook Company, 1939.

Decharge Electrique dans les Gaz, par Marcel Laporte. 222 pages, illustrations, 11 × 17 cms. Paris, Armand Colin, 1939.

Beyond Yonder, by Oliver Justin Lee. 169 pages, plates, illustrations, 14 × 20 cms. Boston, Chapman & Grimes. Price $2.50.

Complex Variable and Operational Calculus with Technical Applications, by N. W. McLachlan. 355 pages, illustrations, 15 × 22 cms. New York, The Macmillan Company, 1939. Price $6.50.

Electrical Engineering Experiments, Theory and Practice, by Henry R. Reed and George F. Corcoran. 500 pages, illustrations, 16 × 24 cms. New York, John Wiley & Sons, Inc., 1939. Price $4.50.

The Meaning of Mathematics, by Cassius Jackson Keyser. Second Edition, 13 pages, 13 × 19 cms. New York, Scripta Mathematica. Price 20 cents.

Thomas Jefferson and Mathematics, by David Eugene Smith. Second Edition, 16 pages, 13 × 19 cms. New York, Scripta Mathematica. Price 25 cents.

Sicily, and the March of Ancient Mathematics and Science to the Modern World, by Robert E. Bruce. 14 pages, 17 × 25 cms. New York, Scripta Mathematica. Price 20 cents.

U. S. Department of Commerce, National Bureau of Standards Miscellaneous Publication M162. Summary Report of Research at the National Bureau of Standards on the Stability and Preservation of Records on Photographic Film, by B. W. Scribner. 17 pages, illustrations, 15 × 23 cms. Washington, Superintendent of Documents, 1939. Price 10 cents.

U. S. Department of Commerce, National Bureau of Standards. Research Paper RP1189. International Temperature Scale and Some Related Physical Constants, by H. T. Wensel. 20 pages, illustrations, 15 × 23 cms. Washington, Superintendent of Documents, 1939. Price 5 cents.

National Advisory Committee for Aeronautics. Technical Notes: No. 712, A Preliminary Study of the Prevention of Ice on Aircraft by the Use of Engine-Exhaust Heat, by Lewis A. Rodert. 17 pages, illustrations. No. 713, A Comparison of Several Tapered Wings Designed to Avoid Tip Stalling, by Raymond F. Anderson. 27 pages, illustrations. No. 714, Flight Tests of Retractable Ailerons on a Highly Tapered Wing, by J. W. Wetmore. 16 pages, illustrations. No. 715, Wind-Tunnel Investigation of an N. A. C. A. 23012 Airfoil with Two Arrangements of a Wide-Chord Slotted Flap, by Thomas A. Harris. 23 pages, illustrations. 4 pamphlets, 20 × 26 cms. Washington, Committee, 1939.

Bell Telephone System, Monographs: B-1131, A Tubular Directional Microphone, by W. P. Mason and R. N. Marshall. 25 pages, illustrations. B-1136, Narrow-Band Transmission System for Animated Line Images, by A. M. Skellett. 7 pages, illustrations. B-1137, Peak Field Strength of Atmospherics due to Local Thunderstorms, by J. P. Schafer and W. M. Goodall. 16 pages, illustrations. B-1138, Rubbed Films of Barium Stearate and Stearic Acid, by L. H. Germer and K. H. Storks. 16 pages, illustrations. B-1140, Cooper Oxide Modulators in Carrier Telephone Systems, by R. S. Caruthers. 23 pages, illustrations. B-1141, Line Problems of the Twelve-Channel Open-Wire Carrier System, by L. M. Ilgenfritz, R. N. Hunter and A. L. Whitman. 25 pages, illustrations. B-1146, Dynamic Measurement of the Constants of Rochelle Salt, by W. P. Mason. 38 pages, illustrations. 7 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1939.

CURRENT TOPICS.

Smithsonian Scientist Finds Sunspot Cycle of 89.36 Years; Discovery May Aid Long-Range Forecasting.—(*Heating and Ventilating*, Vol. 36, No. 6.) A new fundamental time division—the 89.36 year sunspot cycle—has recently been introduced by H. Helm Clayton in a report on mathematical analysis of solar activity issued by the Smithsonian Institution. By means of it, Mr. Clayton shows, he can make fairly accurate predictions not only of the times of recurrence of maximum and minimum numbers of these titanic whirlwinds in the sun's atmosphere of fire, but also their amplitude at different recurrences. The great cycle in turn is split into eight component cycles. These might be likened to eight seasons on the sun, due to some unknown factors in its own physical constitution. Sunspots are attracting constantly more and more attention because of their known and suspected correlations with conditions on earth. They are known to affect the earth's magnetic field and are strongly suspected of exercising a dominant influence over weather. Up to the present, however, means of predicting them have been quite unsatisfactory. It has long been known that there is a basic sunspot cycle, during which the spots increase from minimum to maximum numbers and back to minimum again, which repeats itself approximately every 11 years. This, however, is only an average. In the past 150 years it has been as short as 9 years and as long as 13 years. Nobody has been able to predict with any confidence when a cycle would repeat itself.

R. H. O.

Metal Shot Improves X-Ray Photos of Irregular Objects.—(*Iron Age*, Vol. 143, No. 2.) Metal shot some so fine they float on water, play an important part in the making of sharply defined X-ray photographs of irregular metal objects at the General Electric Co. Should a radiograph of a monkey wrench be wanted, for example, the technicians would pour tiny shot over and about it—spherical particles of copper or steel so small that 10,000,000 of them nestle together in a mere cubic inch of space. The photograph then obtained has all the edges of the parts of the wrench sharply outlined. Had a similar photograph been made with the wrench simply resting on the X-ray negative holder in the air, the resulting picture would have very fuzzy or blurred edges outlining the tool. The explana-

tion, according to C. D. Moriarty of General Electric, is that there is such an emphatic difference in the absorption of X-rays by air and by metals that the part of the X-ray negative not in back of the metal is necessarily over-exposed, with the result that the exposure "spills over" and blurs the edges of the object. Again, when the object being examined has some sections emphatically thinner than other parts, there is a similar fuzziness or blurring of edges of the object.

R. H. O.

Petroleum Reserves.—(*Mining and Metallurgy*, Vol. 20, No. 390.) Engineers are able to estimate with a reasonable degree of accuracy the so-called proved reserves of oil in the U. S. Agreement is general that the quantity is in the range of fifteen to seventeen billion barrels, under the following definition of proved reserves: "The estimated quantity that could be recovered from oil pools or structures already proved by drilling; using methods of production now currently practised; and assuming the product to be marketable at prices approximating those now prevailing." Incidentally, this reserve is roughly equal to "guesses" of the aggregate reserves in the rest of the world made on the same basis; and it indicates a domestic supply fourteen or fifteen times as great as average domestic consumption during recent years. Moreover, despite the production, on the average, of a billion barrels a year for the past fifteen years, the proved reserve today is greater than ever before. That the quantity of oil exploited through wells ultimately will be two or three times the present reserves—at least—no one seriously questions. However, this conjecture is based on geologic speculation and philosophic deduction rather than on tangible evidence. Among the sources of additional oil are the following: Oil in presently known fields that has not been drilled sufficiently to warrant inclusion in the "proved" reserve; oil from deeper horizons; oil from deep pools whose existence is known with reasonable certainty but which have not been exploited because sufficiently deep drilling has not been practical; oil that will be recovered additionally, because of the development of technique and methods for producting more efficient than those now in vogue.

R. H. O.

The Artificial Dissipation of Fog.—(*Chemistry and Industry*, Vol. 58, No. 22.) Many ingenious, but unpractical, suggestions have been at different times advanced to secure the local clearing of fog, particularly at aerodromes. In an article published by the

Institute of Physics in its *Journal of Scientific Instruments*, Prof. David Brunt, Professor of Meteorology at the Imperial College of Science and Technology, gives a critical analysis of possible methods and arrives at some interesting conclusions. Fogs, he points out, are of two main types—"radiation fogs," produced by the cooling of the earth's surface on a clear night, and fogs due to the inflow of warm damp air over a cold surface. The first type is only produced in the absence of any appreciable air movement, and no practical solution to the problem which they present has yet been found. Fogs of the second type have, however, a measurable speed of motion, and in order to produce a patch of clear air, it is sufficient to apply local treatment along a line on the windward side. Prof. Brunt considers heating as a practical method of dissipation. On the assumption that 5 per cent of the moisture in a fog is in the form of droplets, that the temperature increases between the base and the top of the fog by 5 deg. C. and that the rate of drift is 1 meter per second, he calculates that burning 7,500 cub. ft. of domestic gas per minute or 20 gals. of paraffin, would be sufficient to clear a space 100 meters wide to a height of 100 meters.

R. H. O.

The Electromagnetic Levitator.—B. D. BEDFORD, L. H. B. PEER and DR. L. TONKS describe, in *General Electric Review*, Vol. 42, No. 6, this apparatus which causes a disk or shallow dish to be suspended in air by means of applying well known electric and magnetic principles. The force holding the dish aloft arises from the interaction between an electric current in the dish and the magnetic field of the coils and iron core underneath. The force is of the same nature as that which makes an electric motor rotate. The electric currents in the dish are themselves induced by the same magnetic field. The mechanism is the same as that by which current is produced in an electric generator. But in addition to the force overcoming gravity, other forces are provided to restore the dish to the horizontal position if it is tipped slightly, or to push it back to its central position if it is displaced sideways. Such disturbances cause additional currents to be induced in the dish, and these currents reacting on the field, generate the necessary forces. The part of the magnetic field flowing up past the edge of the disk can act as a source of power which it is possible to tap by means of a coil attached to the disk and of slightly larger diameter. This power can be used to run various devices supported by the disk. The fact that all of the magnetic fields originate in the coils of the apparatus makes it possible to transfer signals to the disk which can

control the power generated there, and such remote control features can be added to the device.

R. H. O.

No Matter How You Slice It, It's Still Sausage.—In an article by W. H. HERRING in the *Wooden Barrel*, Vol. VII, No. 10, describing the use of such barrels in sausage-making operations, an interesting bit of history is recorded. The sausage division, Institute of American Meat Packers, affirms that the sausages offered for sale in our meat markets of today are the result of more than 5,000 years' experience in manufacturing the wholesome viand. In Homer's epic poem, the Odyssey, written in the Ninth Century before Christ, reference is made to sausage, the poet citing that it was a favorite food of the Ancient Greeks. Aristophanes, the Greek poet and dramatist, played up sausage in some of his comedies. Babylonian scholars created vivid word pictures of sausage, inscribing them on the stone tablets left behind for the enlightenment of posterity. Sausage was eaten extensively by the Chinese in the days of that great Chinese sage, Confucius, of 551–478 B.C. and it still is, on a very large scale. The Romans had their own type of sausage made, so it is recorded, from fresh pork and white pine nuts, chopped fine and seasoned with pepper, herbs, cumin seed and bay leaves. Other early races of mankind also made sausage and seasoned it in accordance with the kind of spices or other condiments native to the locality in which they lived.

R. H. O.